THE ELEMENTS OF

NATURAL PHILOSOPHY.

ELEMENTS

OF

EXPERIMENTAL AND NATURAL

PHILOSOPHY:

BEING A

FAMILIAR AND EASY INTRODUCTION TO THE STUDY OF THE PHYSICAL SCIENCES;

EMBRACING

ANIMAL MECHANICS, PNEUMATICS, HYDROSTATICS, HYDRAULICS, ACOUSTICS, OPTICS, CALORIC, ELECTRICITY, VOLTAISM, AND MAGNETISM.

For the Use of Youth and Schools.

ILLUSTRATED WITH UPWARDS OF THREE HUNDRED WOODCUTS.

EDITED BY

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PREFACE.

WITHIN the last quarter of a century the rudiments of education have been attained by a vast body of the people; these tools of knowledge being therefore at their command, should be employed in rearing up that mental edifice, perishable only with life, which ennobles the possessor, and by its utility gives world-wide fame to a community.

Science was for a long period clad in antiquated and technical phraseology, causing it to be difficult and repulsive to the popular mind, and requiring for its comprehension a wider field of preparatory study than it was within the power of many to attain. Thus the beauty and simplicity of the laws of nature remained a sealed book to the majority of readers; and the writers on the subject had to charge a high price for their works from the limited demand for them.

Some years ago Dr. Arnott issued his beautiful work on *The Elements of Physics;* in which frigid, uncouth, and learned terms were discarded, and the sciences unfolded in all the lovely simplicity of their nature, adorned only by poetic language called forth by the sublimity of the subject. This work has unfortunately been long out of print; while its price rendered it only the interesting and instructive companion of the favourites of fortune. Since its publication science has made gigantic strides; every day now reveals some new wonder, or useful and hitherto unthought-of application.

We have ventured on the same path as the learned Doctor, but not without a consciousness of the vast difference in our capabilities; still we trust we have produced a useful work; every pains has been taken to give such illustrations as may enable the eye to help the mind to comprehend when the ear cannot.

The subjects of which this work treats are as intensely exciting as a powerfully-drawn romance; with this difference, that the passions are not played upon, but the moral feelings aroused, the pleasure of life

increased, and our reverence, awe, and love of the Creator deepened by a knowledge of the phenomena with which nature surrounds us.

It is due to Eneas Mackenzie, Esq. to state, that a portion of this book was written and arranged by him, before it fell into the hands of the present Editor, who would, moreover, take this opportunity of expressing his warm acknowledgments to Dr. Neil Arnott, F.R.S., for the use he has been permitted to make of his invaluable book, the *Elements of Physics;* to Professor Robert Hunt; to F. H. Holmes, Esq., Professor of Natural Philosophy to the Royal Panopticon of Science; to James Glaisher, Esq., F.R.S., E. M. Clarke, Esq., and other esteemed friends.

That this volume should not proceed to a more expensive and cumbersome length, it has been thought advisable to glance merely at some of the more interesting parts of the various subjects with which we have to deal, and to present them in a more extended form as separate volumes; this has been done already with Mechanics, Electricity, Astronomy, Geometry, &c., which are published uniformly with this work.

To aid the progress of our countrymen to that mental position their untiring industry merits, to fertilise the seeds of genius, to promote sound education, to give that elevating tone to the popular mind so productive of happiness, to implant a love of knowledge in the minds of youth, with a full appreciation of the wonders of the works of God, has been the desire, the aim, and the end of

THE EDITOR.

Gower Street, Bedford Square,
June, 1853.

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INTRODUCTION.

" There is a voiceless eloquence on earth,
Telling of Him who gave her wonders birth;
—— Whose hidden but supreme control
Moves through the world, a universal soul."

IF we examine the mere signification of the two words NATURAL PHILOSOPHY, we find that natural means something that is produced by nature; and philosophy, from the Greek, is literally "love of wisdom or knowledge." Thus, then, the words imply love of a knowledge of the productions of nature or God. Knowledge, in its true sense, is an accumulation of facts; these man carefully collects, and reasoning thereupon, is capable of penetrating many of the secret workings of nature, and turning such acquisition to his peculiar advantage. Natural Philosophy is also termed PHYSICS; that is, a study of nature by means of the strictest modes of investigation the intellect of man has at command.

Man cannot form any of the materials of nature; but by a knowledge of their properties he may shape them to his own use, which is called Art. He must have studied the peculiar quality of iron-stone before he knew the treasure it contained; the effect of heat upon it he must have tried before he could fabricate the rough chisel to rend from the quarry and fashion the stone under which he found shelter. The iron and stone are the productions of nature; the chisel, the form of the stone, and the house, are the efforts of art.

Wide is the scope of Natural Philosophy. It leads to an acquaintance with the laws that keep the planets in their undeviating path; it treats of the phenomena of the earth, the air, and the ocean; of the simple principles of mechanism that man employs; of the falling of the silent dew or the rushing of the roaring cataract; of the heat of summer and the frost of winter; of the zephyr-breeze or the destructive tornado; of the swim-

ming of fishes or the flying of birds; of the ripple of the placid lake or the mountain waves of the ocean; of the grace, motion, and powers of the human form; of the mechanism of the voice, the ear, and the eye.

By an acquaintance with its first principles—the embellishments of a palace, the necessities of a cottage, the swinging of a carriage, and the management of a dray, are all better accomplished. The elasticity of air and steam, that drives the vessel despite of tide or wind, or sends tons of merchandise with surprising velocity to the extremes of a kingdom, are by its teaching comprehended. Knowing the cause of the awful voice of thunder, of the terrific destruction of lightning, and of the peaceful beauties of the rainbow, much ignorant teaching is dispelled. Man has so advanced in his comprehension of nature, that he chains one of the most fearful elements to his use, which he guides and directs as if it were possessed of the feebleness of a helpless babe; with it he sends his thoughts with a speed surpassing the rapid flight of time. No one can feel but abashed at not understanding the simple principles that produce such seemingly miraculous effects.

Natural Philosophy aids, then, our commerce, wealth, happiness, luxuries, necessities, and civilisation.

Goldsmith writes, "The blushing beauties of the rose, the modest blue of the violet, are not in the flowers themselves, but in the light which adorns them: odour, softness, and beauty of figures, are their own; but it is light alone that dresses them up in their robes, which shame the monarch's glory." The properties of light form an important portion of this science. Prince Albert has given an epitome of the utility and importance of Natural Philosophy. "Man," observes the noble and enlightened Prince, "is approaching a more complete fulfilment of that great and sacred mission which he has to perform in this world. His reason being created after the image of God, he has to use it to discover the laws by which the Almighty governs his creation, and by making these laws his standard of action, to conquer Nature to his use—himself a divine instrument. Science discovers these laws of power, motion, and transformation; industry applies them to the raw material which the earth yields us in abundance, but which becomes valuable only by knowledge."

> "How charming is divine philosophy!
> Not harsh and crabbed, as dull fools suppose,
> But musical as is Apollo's lute,
> And a perpetual feast of nectar'd sweets,
> Where no crude surfeit reigns." MILTON's *Comus*.

MATTER AND ITS PROPERTIES.

ATOMS.

THE earth that we tread upon, the rocks that we build with, the metals that we use, the trees of the forest, the herbage of the fields, the waters of the globe, the animals that exist—in fact, the whole visible universe is formed of minute imperishable grains of matter, which learned men have agreed to call ATOMS. The word "atom" is derived from the Greek, and signifies that which cannot be cut into smaller particles.

On pointing a piece of slate-pencil, a dust is produced, parts of which may be so small as to be beyond the powers of the human eye to distinguish; yet, on placing them under a microscope, it will be discovered that they may be ground still smaller, until even the magnifying powers of the instrument can hardly make them visible. By chemical means they may be entirely lost to man's sight, aided though it be with his beautiful optical inventions; still, the atom has not ceased to be, it has only combined with some other matter, and the practised chemist can again separate it without the slightest loss of substance.

If a piece of paper, coal, or wood be burnt, there exists no less matter than before; all that has taken place is a change of arrangement or combination of atoms.

When the human body becomes the inhabitant of the grave, and all visible remains are a mere handful of dust, the gases in which its substance has vanished have added to the growth of the vegetable kingdom—commingled with the atmosphere—exist as an active living portion of other matter—and not an atom is lost to the material world.

The term *molecules* is much used by writers on science, by which they mean the infinitely small material particles of which bodies are conceived to be aggregations.

DIVISIBILITY OF MATTER.

It is an evident fact, that every portion of matter, however small or thin, must have an upper and an under surface, and it follows that they can be separated; but in some materials a difficulty exists of increasing the surfaces.

A bank-note, which is printed on extremely thin paper, by being pasted on calico, may be separated; this gives two surfaces more to the paper, and it covers twice the space it did before the operation.

The workers in metals, by pressure or heat, increase the surfaces of their materials, so as more easily to fabricate their useful wares.

In the streets, projecting from a house, is often to be seen the sign of a gilded brawny arm, having a hammer in the hand; and by entering the workshop some wonders of the goldbeater's art may be learned. A single grain in weight of gold can be hammered until it will cover a space of fifty square inches, and this may be divided into two million pieces, visible to the eye, which is forty thousand parts to each square inch.

With the assistance of the microscope, the grain of gold may be seen divided into fifty million distinct parts.

A pound of silver contains 5760 grains; and one grain of gold mixed with the silver spreads through the whole mass—that is, into 5760 parts. By applying aqua-fortis, the gold is separated, and as entire as before the mixture.

Gold-leaf, as used to make picture-frames and other things appear like solid gold, is so thin that 1500 leaves are not thicker than the paper of a page of this book; 291,000 leaves would only be one inch thick. Wonderful as this handicraft of the goldbeater may appear, the mechanic yet exceeds it when he prepares material for the coating of silver wire to form gold lace, as he then makes a single grain cover upwards of 10,000 square inches, and not a four-millionth part of an inch in thickness.

A wire may be drawn nearly 400 miles long, and entirely coated by an

ounce of gold : thus, little more than 60 ounces of gold would gild a wire to put a girdle round the world.

Dr. Wollaston drew platinum into such fine threads, that 140 of them were no thicker than a fibre of silk.

The chemist can by a stream of hydrogen gas reduce the oxides of some metals into atoms less than the one hundred and six millionth of an inch in diameter, so that a cubic inch of them would cover more than five acres of land.

A soap-bubble, consisting of water and a hundredth of its bulk of soap, was proved by Newton not to be quite the two million six hundred thousandth part of an inch in thickness! How minute, then, must be an atom of soap! It almost surpasses comprehension, and would require an array of twenty-two figures to express its size.

The seeds of some fungous plants are so small, that they appear like smoke; and yet they perform all the operations that cause them to become living plants.

A pound of wool has been spun by the hand into a thread 160,000 yards in length; and a pound of cotton, or 7000 grains, by the aid of the wonderful machine, the "self-acting mule," can give a thread equal in length to 476,810 yards, or 248 miles!

A hundred yards of the raw silk of the silk-worm does not weigh a grain; and it has to be many times doubled and twisted to form a fine thread for domestic use. Still finer are the fragile threads of the spider, which, proceeding from four thousand holes in the little animal, are all twined together to form one slight beautiful gossamer line.

As far as man can penetrate into the minuteness of nature, with the utmost help of his ingenuity, he discovers living animals, perfect in formation, active in their movements, obeying natural laws, and yet a million of them do not take up more space than a grain of sand. Each of these must be again divisible; and who can say they are the smallest of animal formation? Part of the towns of Berlin in Europe, and of Richmond and Petersburg in America, stands on a bed of earth which the microscope has proved to be a mass of fossil animalcula: how wonderfully minute, when a handful contains billions of individuals once possessed of organs of digestion, motion, feeling, and reproduction! The fine polishing powder called *tripoli*, so largely used in the arts, consists entirely of the invisible siliceous shells of animals: how inconceivably small must each part of them be, when 220 grains contain "upwards of forty thousand millions of individual organisms!" The mud thrown up yearly on the banks of the "hoary Nile" does not result, as was supposed, from the washed-down *débris* of the mountains; but is composed almost entirely of a "multitudinous accumulation of infinitely minute living forms of animal life, wholly undiscernible to the naked eye in themselves, but in the mass constituting no inconsiderable portion of the solid soil." Who, then, can set a limit even to the divisibility of organic matter? A man could hold in his hand more of these minute animalcules than there are of mankind in the whole world.

Minute, however, as we have shewn many things to be, there are some, sensible to our senses, still more so. Odour is known to be the disengagement of particle sof a substance; small, then, must be the atoms of musk! During twenty years, a grain has perfumed an apartment

where the air was frequently changed; and after all these years, diffusing itself into millions of cubic feet of air, its diminution of weight could hardly be estimated.

The vulture and carrion crow will smell their food at many miles distance, although the wind be in a contrary direction.

A perpetual unceasing change is always going on in the material world, and the whole is a system of destruction and reproduction. Man, animals, vegetables rapidly fall and decompose, but only to be renewed and live again in other combinations. The substance of man becomes the food of plants—plants become the food of animals, and animals that of living man. The divine spiritual principle, the soul, is the only criterion by which we can say what constitutes the difference between life and death. Of atoms there are never less, never more, and they are ever in a state of transition.

RESISTANCE OF MATTER.

Impenetrability is the word used in science to express this branch of our subject. In plain language, it means that every atom of matter occupies a certain space which cannot be occupied at the same time by another atom. Thus, one part of matter is said to resist another part taking its place, as matter could not be without having a place to be in. One marble cannot be forced into another, and so occupy the same place as one; if such a thing were possible, the whole world might be placed in a nutshell. If a nail be driven into a soft piece of wood, the spaces between the fibres are lessened, but the atoms composing the wood remain as entire as before.

All children know, when amusing themselves with a squirt or syringe, and they fill it with water, then stop up the pipe, if the piston be tight, their utmost strength cannot force it down; the cause is, that the water will occupy space, and resists any other body that attempts to displace it. If the syringe were strong enough, more than the weight of St. Paul's Cathedral might be supported by the water. Even when the syringe is what we call empty, and the pipe stopped, the piston resists being forced down, because the air it contains must have space as well as other things.

A bottle plunged neck downwards in water will not fill with the fluid, as it is already full of air which cannot escape.

If a glass be turned up and forced into water, the air, being elastic, slightly gives way, and the rest resists the water filling it. A diving-bell is a useful practical illustration of this fact. A little floating light would burn a short time underneath, and might thus illuminate the bottom of the sea.

Should a person accidentally fall into water, and have the presence of mind to seize his hat and hold it in the same position as when on his head, the resistance of the air in the hat would aid him in supporting his body.

ATTRACTION.

The dust, grains, or atoms, in all varieties of shape and size, adhere or cling together by a power called ATTRACTION. This unseen power binds the atoms into masses of matter; but it varies in force, as we find on crumbling a piece of chalk, and attempting to do so to a piece of marble:

the one is easily separated, the other requires more power than the fingers possess.

That there is a limit to its influence is proved by its being overcome; as is done on reducing large hard substances into dust or vapour.

The ripe apple, or the falling stone, attraction draws towards the centre of the earth; and by it the planets in the heavens are kept in their orbits. Whether it be in Europe, Asia, Africa, America, or Australia, all things, at all times, are attracted to the centre of the earth. Thus: be it noon, and our heads are towards the sun, or midnight, and our feet point to it, all things press towards the centre of the earth; and it is this power of attraction that gives stability to the sea, land, and the erections of man resting on a round, twirling globe.

Weights.—If we have two bags the same size, one of them filled with wool, and the other with sand, we say, the bag of wool is light, the bag of sand is heavy. The fact is, the sand consists of more matter than the wool; and as every atom is attracted, there exists more attraction, and thus weight is attraction.

Large bodies attract smaller, and are themselves attracted by the smaller: thus the action is mutual. The sun attracts all the planets of our system of the universe, and the moon attracts the waters of our ocean and produces tides. The various planets, by their powers of attraction, affect the motions of each other; and it was by noticing this effect, that the exact position of the planet Neptune was pointed out, before it had ever been seen as a planet. Two bullets suspended at a height above the earth, will, by attraction, not hang in a direct line, but lean towards each other, the lines pointing to the centre of the earth, forming an angle with each other; this is not very observable at small distances, but nevertheless always is the case. A plummet hung from a mountain-top inclines towards the side of the mountain; but the earth being the larger body, the attraction is greater towards it.

The highest of the Andes from attraction draws a plumb-line from the perpendicular about 7″; and these experiments have led to a knowledge of the earth being 5·6747 times the density of water.

Fluids from attraction assume the form of the sphere or globe, from being that in which the atoms have the greatest proximity. Thus, lead dropped through a sieve, from a high place, forms round shot; water, whether as the glistening tear, the spray of the oar, the rain from the clouds, the dew on the plants, or the hail of winter, all possess roundness; and from this fact philosophers argue that the sun, moon, stars, and planets have at one time been fluid.

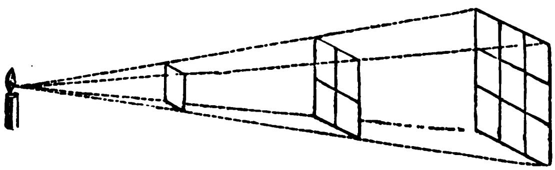
The rising of smoke, the sailing of balloons, the floating of light bodies, arise from the air or water possessing more matter in a given bulk than the bodies named; and therefore being more forcibly drawn to the earth, they sink below, and force upwards the smoke, balloons, or other lighter bodies.

Mutual Attraction may be seen, when two drops of water, or mercury, are in contact; they mutually spring to each other, and form one mass.

When a person leaps from the earth, on descending, the earth rises to meet him: this is the case with the smallest atom; but as the attraction acts comparatively to the bulk, and the body of a man is very small to the size of the earth, the movement is imperceptible. The immutable law of

attraction likewise acts at immense distances as certainly and continuously as near at hand: the planet Herschell, 1,800,000,000 miles distant, has its motions, position, and existence, from this law, as have all the other heavenly bodies in the universe.

"The attractive force is inversely as the squares of the distances," write scientific men. That is, heat, light, and attraction being most intense when near, gradually decrease as the object is further off, which decrease can be exactly told by figures. This is exemplified by lighting a candle, and placing, at three feet distance from it, a board one foot square, then at three feet distance from that board, another two feet square, which will have a surface of four square feet: it will be seen that the one-foot square board entirely prevents any light falling on the two-feet square board. Place another board, three feet square, having a surface of nine square feet, three feet from the two-feet square board, that is, nine feet from the candle,



and it receives no light: now remove the one-foot board, and the light that was spread over it falls upon the two-feet board, diffused over four square feet, thus four times less intensely; again, remove the two-feet board, and the light falls upon the three-feet board, and is spread over nine feet, consequently is nine times less intense.

Say attraction commences at an inch, a foot, or a yard: at twice the distance, it is only one-fourth, at three times one-ninth, at four times one-sixteenth, at five times one-twenty-fifth; and thus multiplying each distance by itself, as six times six are thirty-six, the exact extent in which attraction, heat, or light is decreased may be found.

Attraction being weight, as bodies are removed to a distance, their weight is decreased. Thus, a body weighed at the mean level of the earth's surface, that is, at the sea-shore, will be found to weigh less if carried to a mountain-top or up in a balloon, because they are so much further from the point of attraction. But as the scales and weights would be equally affected, a spring-balance would have to be used.

A substance weighing 1000 pounds at the level of the sea, on being carried up a mountain four miles high would weigh two pounds less. A body at about 1656 miles from the earth would lose half its weight.

At the north and south poles the parts being flattened, the earth is termed a spheroid, that is, not exactly round, but approaching the form of a sphere or globe. From this circumstance of its shape, the attraction is $\frac{1}{590}$ greater at the poles than at the equator; but there being no centrifugal force at the poles, bodies will on that account weigh $\frac{1}{285}$ at the poles more than at the equator; the sum of these two fractions $\frac{1}{195}$ will express the whole difference in weight of the same body carried from the equator to the poles. Thus, 194 lbs. at the equator will weigh 195lbs. at the poles.

Newton and Laplace stated from theory that gravity *increased* at the poles, and *decreased* at the equator. They proved the correctness of their theory by shewing that a seconds pendulum had to be longer at the poles than at the equator. Now suppose a spring-balance to be hung at the pole,

and a weight representing a thousand pounds be the bob, which weight just grazes the earth, remove this balance carefully to London, and the bob or weight will be found not to touch the earth from the decrease of gravity; and to bring it down to the ground, an additional weight, or rather so many more atoms of matter, must be added to cause as much gravity as existed at the pole.

Again, if a ship be loaded at St. Thomas's Island, say 1000 tons, and it sail to London, for that ship to be of the same weight, there must be so many pounds taken off, because the gravity or weight has increased, being so much nearer the pole. If deeply laden, danger might be apprehended.

Sir John Herschell states, that 100,000 pounds at the equator would weigh 100,315 pounds in London, which arises from the variation of attraction from the form of the earth.

There are different terms given to attraction, to distinguish particular modes in which it acts: thus, there are *Attraction of Gravitation, Cohesion, Capillary, Chemical, Magnetic,* and *Electric.*

Attraction of Gravitation is the power that all masses of matter exert upon each other at all distances; and, according to the quantity of matter, so is its gravity, so its weight. The largest mass of matter being at the earth's surface, there is gravity greatest: as we penetrate into the bowels of the earth, the matter becomes less, and bodies weigh consequently less; if we could gain the centre, attraction being equal, the body would have no weight, and remain suspended.

A pound weight at the earth's surface, at 1000 miles depth would weigh three-quarters of a pound; at 2000 miles depth, half a pound; at 3000 miles, a quarter of a pound; and at 4000 miles, the centre, it would have no weight.

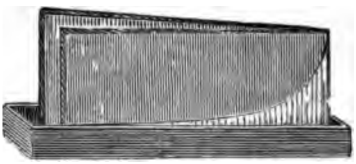
We have already mentioned the orbits of the planets and the tides as proceeding from attraction, and the effects produced when one planet approaches another. It is this power which keeps the aërial ocean in which man lives pressed down, grasped to the earth, and causes it to rush into every empty space as soon as such exists. Gravity thus acts as a binding substance to all things on the earth, and retards bodies from proceeding from it. Gravitation acts upon things at a distance, however remote they may be.

Attraction of Cohesion.—Cohesion, or sticking together, is the name of that attraction which binds atoms when close to each other in different forms and sizes, whether it be the atoms of the marble quarry formed by nature, or the iron poker fabricated by the hand of man. It differs from gravitation, as it only takes place when the atoms are so near each other that they appear to be in close union; and it is this seeming contact that so greatly increases the attractive power, as attraction greatly increases by nearness. It exists strongest in metals, decreases in other solids, and is least of all in fluids.

Capillary Attraction.—The word "capillary" is derived from the Latin word *capilla*, a hair; and as we know a hair is a tube, it signifies the attraction of a fluid by a solid having tubes or pores.

By placing in some water tubes of glass having different-sized bores, it will be seen that the water will rise in the tubes—highest in the smallest-sized bore, and gradually less as they are larger. If two panes of glass be placed upright a little way in water, touching at one of the upright edges and a little open at the other, the water will rise up between them,—higher

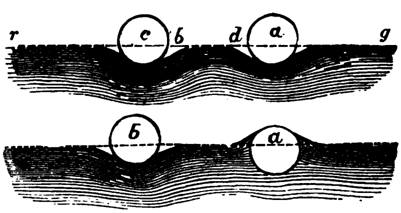
at the part where they touch, gradually lessening, in a beautiful curve, towards the open edges. If a damp stick be put into water, the fluid rises up the stick above the level of the other water. A sponge, a piece of blotting-paper, loaf-sugar, or salt, if allowed just to touch water, rapidly takes up the moisture, which rises until the entire piece be filled. By the river-side we see pieces of straw, chips,



and other light bodies, clinging to each other, whirling in the eddies, and keeping on their journey together; balks of timber, in concert, hurrying along rapids, and light substances huddling together in ponds. Two pieces of cork swimming, when within a short distance join each other, and proceed onward in companionship.

When from capillary attraction water rises in a glass tube, its surface is hollow or concave, the curve of which is according to the attractive force of the sides of the tube; but if the inside of the tube be greased, then the water is repelled, and the surface is like a dome or convex: this is also the case when the fluid will not moisten the surface of the solid, as a glass tube placed in mercury.

Under the head of capillary attraction is placed that singular attraction and repulsion of small floating bodies. The Abbé Haüy thus illustrates it: If *a* and *c* be two balls of wax floating on water, and the distance between them small, they will approach towards and join each other, because both of them repel the water at *d* and *b*, causing it to be hollow, while the pressure of the water at *g* and *r* force them together, and thus there appears an attraction.



In fig. 2 *a* is a piece of wetted cork, and *b* a ball of wax. The cork draws the water around it, and the wax repels it; hence, when the balls are placed together, they seem to repulse one another, from *a* attracting the water which *b* repels, as it is not capable of capillary attraction.

A towel, with one corner in a basin of water, will absorb the water until it is completely saturated.

A piece of wood driven into a solid stone, and water thrown upon it, will fill its tubes, and rend the stone into pieces, with a power exceeding 700 pounds on each square inch. Quarrymen in Germany practise this method. Slate is often split in the same manner.

A writer in the *Mechanics' Magazine*, instancing the power of moisture as a method by which millstones are procured, states, that when a mass of proper stone has been found sufficiently large, it is cut into the form of a cylinder, several feet in height; and the question then is, how to cut it into horizontal pieces, to make as many millstones as is deemed proper. For this purpose, circular and horizontal indentations are cut out quite around it, and at proper distances, according to the thickness to be given to the millstones. Wedges of willow, dried in an oven, are then driven into the indentations, by means of a mallet. When the wedges have sunk to a proper depth, they are moistened, or exposed

to the humidity of the night, and next morning the different pieces are found separated from each other. Let us now suppose the diameter of one of the capillary tubes of the wood to be only the one-hundredth part of a line, that the inclination of the sides is one second, and that the force with which the water tends to introduce itself into a tube is the fourth part of a grain. This force, so very small, will tend to separate the flexible sides to the tube, with a force of about 50,000 grains, which make about $8\frac{3}{4}$ lbs. In the length of an inch let there be only fifty of these tubes, which gives 2500 in a square inch, and the result will be an effort of 21,875 pounds. As the head of a wedge of the kind above mentioned may contain four or five square inches, the force it exerts will be equal to about 90 or 100,000 pounds; and if we suppose ten of these wedges in the whole circumference of the cylinder intended to form millstones, they will exercise together an effort of 900,000 or 1,000,000 of pounds.

The wick of a candle and the cotton of a lamp act as tubes in bringing up the grease or oil to the flame.

In dry weather we see the men in barges throw water on their sails, which is for the purpose of swelling the fibres, or the capillary tubes, of the fabric, and thus forming a closer texture to hold the wind.

A great weight resting on the ground, attached to a tight rope, may be raised by wetting the rope. It is from this circumstance of the immense tightening of wetted ropes, that, when vessels are at sea, and rain comes on, the sailors slacken the ropes.

Illustrative of the effects of moisture, there is a most excellent story. Even if it be a romance tacked on to an historical fact, still it is so impressive of the truth of a principle that it merits notice. In the piazza before St. Peter's at Rome stands the most beautiful obelisk in the world. It was brought from the Circus of Nero, where it had lain buried for many ages. It is one entire piece of Egyptian marble, 72 feet high, 12 feet square at the base, and 8 at the top, and is computed to weigh above 470 tons, and supposed to be upwards of 3000 years old. Much engineering skill was required to remove and erect this piece of art, and the celebrated architect Dominico Fontane was selected and engaged by Pope Sextus V. to carry out this difficult operation. A pedestal 30 feet high was built for its reception, and the obelisk brought to its base. Many were the ingenious contrivances prepared for the raising it to its resting-place, all of which excited the deepest interest amongst the people. At length every thing was in readiness, and a day appointed for the great event. A great multitude assembled to witness the ceremony; and, afraid that the clamour and curiosity of the people might distract the attention of the architect, the Pope issued an edict containing regulations to be observed, and imposing the severest penalties on any one who should, during the lifting of the gigantic stone, utter a single word. Amidst suppressed excitement of feelings and breathless silence, the splendid monument was gradually raised to within a few inches of the top of the pedestal, when its upward motion ceased; it hung suspended, and could not be got further; the tackle was too short, and there seemed no other way than to undo the great work already accomplished. The annoyed architect in his perplexity hardly knew how to act, while the silent people were anxiously watching every motion of his features to discover how the problem would be solved. In the crowd was an old British tar; he saw the difficulty, and

how to overcome it; with stentorian lungs he shouted out, "*Wet the ropes!*" The vigilant police pounced on the culprit, and lodged him in prison; the architect caught the magic words, he put this proposition in force, and the cheers of the people proclaimed the success of the great undertaking. Next day the English criminal was solemnly arraigned before his holiness; his crime was undeniably proved, and the Pope in solemn language pronounced the sentence to be—that he receive a pension annually during his lifetime.

Chemical attraction or *affinity* is when the atoms of two or more different substances unite into one perfect compound. Dr. Arnott remarks, that whether the different substances or kinds of matter "are in truth originally and essentially different, or are all only the one simple primordial matter, modified by circumstances as yet unknown to us, we cannot now positively determine. Diamond and pure black carbon are the same substance, only the atoms are differently arranged; and the soft steel which the graver cuts as it would copper or silver is exactly the same substance as when, after being tempered by heating and sudden cooling, it has become as hard nearly as diamond itself. Yet these differences are greater than appear between some substances which we now account essentially distinct. It is found, however, that the atoms of what we call different substances will not cohere and unite indifferently, as atoms of the same kind do, there being singular preferences and dislikes among them, if it may be so expressed; and when atoms of two kinds do combine, the resulting compound generally loses all resemblance to either of the elements. Thus: sulphuric acid will unite with copper, and form a beautiful translucent blue salt; with iron it will form a green salt; and if a piece of iron be thrown into a solution of the copper salt, the acid will immediately let fall the copper, and take up or dissolve the iron. Sulphuric acid will not unite with or dissolve gold at all. Quicksilver and sulphur unite in certain proportions, and form the paint called vermilion; in other proportions they form the black mass called Ethiop's mineral. Lead and oxygen gas from the atmosphere form together what is called red lead, used by painters. Sea-sand, or flint, and the salt called soda, when heated together, unite and form that most useful substance called glass. Certain proportions of sulphur and of iron combine, and produce those beautiful cubes of pyrites, or goldlike metal, which are seen in slate. Chemical attraction, operating thus, does not in the slightest degree interfere with general attraction or gravity, for every chemical compound weighs just as much as its elements taken separately."

Gases permeate different substances, which is the principle of capillary attraction; their facility for so acting depends on the density of each particular gas, in fact inversely in proportion to the square root of its density.

COMBINED HEAT.

Thus far we have seen that matter is composed of atoms; that gravitation acts upon bodies at a distance, cohesion on atoms close to each other, and capillary attraction on solids and liquids; but what the size of an atom is, or what attraction is, are mysteries of the Creator.

No atom touches another atom; but how far they are apart in what we call solid substances, whether it be many times their own bulk, we cannot define.

Sir John Herschell says, why may not the atoms of a solid be as thinly distributed in the space it occupies as the stars that compose a nebula?

Were there not a modifying power, the atoms of which the material is formed would so join as to be one hard mass: the modifying power is one of which we know as little as of some other universal principles; it is said to be HEAT; but according to Mr. Holmes' theory it is repelling atoms.

Heat produces solid, liquid, and gaseous forms of matter, according to the quantity in which it exists. It causes bodies to expand, that is, the atoms to be further apart, and this is called *repulsion*. The greater the heat, the greater the repulsion.

Count Rumford states that with twenty-eight grains of gunpowder he filled a cylindrical space, and having ignited the powder it tore asunder the iron which would have resisted a strain of 400,000 lbs.

If water be dropped on red-hot iron, it never touches the iron, but forms into round globes and evaporates as steam. Engines projected to be moved by steam thus generated, instead of having a boiler for the purpose, would have a plate of iron constantly red-hot.

When water is poured on a red-hot sieve, it will not pass through until the sieve becomes cool.

Heat is discovered in all things, in some more than in others; and it being a universal principle, there does not exist anything from which it is entirely absent. Solid ice, when heat is applied, becomes water; applying more heat, the water becomes vapour: reduce the heat, and the elastic fluid is once more water; and by further extracting heat, the water is again ice.

Heat does not add to the perceptible weight of a substance; therefore scientific men call it imponderable, that is, having no weight; and to the cause of heat they give the Latin name *caloric*.

Even the heat of the atmosphere in summer, and the decrease of it in winter, sensibly affects large bodies of iron. In that wonderful triumph of science by Robert Stephenson, the tubular bridge across the Menai Straits, there is provision made for the effects that will be produced by changes in the temperature of the seasons. The entire length of the tube is 1832 feet 8 inches, and the extent of the motion hitherto observed in each half is 3-16th of an inch. By a simple contrivance, a daily self-acting record is given of the amount of its contraction and expansion.

The yard, which is our standard linear measure kept by the Government, has always to have a certain temperature of atmosphere to be exact.

A delicate simple machine is used for the purpose of ascertaining the dilatation of iron by the application of heat. It is called a pyrometer, or fire-measurer.

A cubic inch of water, weighing 252 grains, by heat may be expanded, that is, the atoms repulsed, to such a distance as to fill a space of 1987 cubic inches.

A piece of iron that exactly fills a hole when cold, will by heat become so swelled that it will not enter the same place.

In our workshops, the iron hoops upon a mast, cart, or coach-wheel, are put on hot, and then suddenly cooled: the contraction of the iron causes it to grip and bind more surely and strongly than could be effected by any other means.

A bladder filled with air, and placed before the fire, will burst from the expansion of the air by the heat.

Mercury expands from heat, and is used to measure in various instruments the degree in which heat exists.

Lamentable accidents have occurred by the iron beams of buildings

contracting from cold, and thus bringing down the whole structure to a mass of ruins; while in some buildings a bulging wall is brought back to its position or saved from falling by inserting pieces of hot iron, and int hat state screwing them tightly up; when the iron cools, it contracts, and either restores the straightness of the wall or binds it tightly.

Latent heat—that is, hidden heat—is found in ice, wood, iron, cloth, water, and other substances; but we are not, by feeling, aware of its presence.

Schoolboys know, by rubbing a metal button on a smooth substance, that they amuse themselves by the heat they have created—which is sufficient to fire and burn phosphorus.

The natives of Australia produce fire by rubbing two pieces of wood together.

Ice by being rubbed against another piece will melt.

A blacksmith will beat a piece of cold iron until it is sufficiently hot to light his fire or his pipe.

If a bundle of tightly-packed rags be wetted, the latent heat is aroused, and the rags burst into flames; this has caused some lamentable accidents at sea.

Stacks of hay and corn have been known to take fire from being piled damp, or from rain penetrating beneath their surface.

Not many years ago, a serious fire broke out at one of our dockyards from some greasy clothes being thrust away with other rubbish.

The extraordinary mountains of fire seen in Northumberland and Durham are the small refuse coal which is cast down near the mines, and rain being absorbed, the latent heat causes it to ignite, illuminating at night miles around, and tinging the sky with fiery lustre.

A coach-wheel, not well greased, turned rapidly round, takes fire.

An end of a rod of glass held to a grit-stone while revolving, accumulates heat sufficient to fire gunpowder.

The iron part of a saw or gimlet, after being used, becomes so hot that the hand cannot take hold of it.

On grinding a knife, sparks of fire are emitted from the iron and stone.

A flint and steel struck against each other, or a lucifer-match, produce fire, although no heat can be felt previously in any of the substances.

A small piece of grit underneath a rolling barrel of gunpowder was the supposed cause of the awful explosion and painful circumstances at the Hounslow Powder-Mills in 1850.

Compression will cause heat to be evolved from air. A small piece of tinder placed at the lower extremity of a syringe, and the piston being drawn up, then driven back by a smart blow, the sudden condensation of the air fires the tinder.

It is the latent heat contained in steam that enables us to convey it to a considerable distance in pipes, and use it in heating buildings, baths, and other useful purposes.

SENSIBLE OR FREE HEAT.

The solid, liquid, or gaseous state of bodies, then, seems to be the result of temperature; not a lasting condition, but one ever varying. In solids, the attractive force is more powerful than the repulsive; fluids may be considered in a middle state, the two antagonistic powers being about

balanced; while the aëriform is one in which repulsion is more powerful than attraction.

The skill of the chemist has taught us how to cause metals, earths, and liquids to assume all these different forms, and that we must employ different degrees of heat and cold in the operations. The rule is almost universal, that bodies which need the longest time to heat, also take the longest time to cool: this is easily tested by placing water and mercury before the fire. It is worth noting, as shewing the different capacities for heat in different fluids, that two measures of the same heated fluid mixed will contain the same degree of heat; but a pint of one fluid and a pint of another will contain different degrees of heat.

A certain intensity of heat is requisite to render particular metals fluid; the greatest in Wedgewood's scale is for melting cast iron, then silver, next gold, and brass follows; to boil mercury, to melt lead, and then tin; decreasing to a heat at which milk boils, and next water: but many metals require a higher degree of heat for their fusion than that which would melt iron.

There is a particular point of temperature at which each liquid boils; water at 212°; mercury, 670°; alcohol, 176°; ether, 98°; and when at this heat, it cannot be increased, that is, these substances cannot be made hotter. The application of more heat under the ordinary pressure of the atmosphere only further repels the particles until the gaseous state is assumed; but if the pressure be reduced, then all liquids boil at a lower temperature; thus when the barometer stands at 28 inches, water boils at 209°.

A little piece of potassium—a metal which when united with oxygen forms potash—if placed on ice, will take fire and burn with a flame, and quickly dissolve the ice.

Steam when perfect is invisible; but when it meets with a colder temperature it condenses, and it is the condensation that makes it visible. A cubic foot of water will as steam occupy 1700 feet, and will require six times the quantity of heat to raise it into steam that it did to make it boil.

There is no simpler illustration of the state of matter being consequent upon the degree of heat than the idea of the hardness of common sealing-wax. We have to apply the heat of a candle to melt it, and it speedily becomes hard again; while the Post-office orders that letters going to India must not be sealed with it, as on the passage in warm climates it melts, and causes all the letters to adhere together. Butter and tallow cannot be kept in a stiffened state at the equator; while our north-pole adventurers reverse the story, and we hear of the freezing of oil and mercury.

REPULSION AND COHESION WITHOUT SENSIBLE HEAT.

Heat, it has been seen, causes repulsion; but repulsion takes place in many things without our being sensible of heat, making it appear as if some invisible matter surrounded objects and prevented their cohering.

Enter a garden in the morning and examine the dew-drops on a flower, or, better still for illustration, on a cabbage-leaf: the round drops of dew will be seen rolling down the leaf, not leaving the slightest wet upon the plant, while light is reflected from the under surface of the drop, which shews that the dew never touches the leaf, but is repulsed.

Watch the drops of water on the back of a duck, and the same repulsion is seen in force.

Newton calculated this invisible power, and found that a globe of glass placed on a smooth surface of the same material did not touch, and a pressure of a thousand pounds on an inch would not make them do so. He stated the distance to be the 10,000th part of an inch; and that though by force the distance might be reduced, he questioned the contact ever being made quite perfect by pressure only.

In the play-ground, when an iron hoop is broken, the misfortune cannot be repaired by forcing the parts together, because repulsion of the parts prevents it; to mend it, the parts must be heated and beaten together, which is called welding,—a property possessed by this metal and platinum only.

Beautiful strong shirt-buttons are made from China clay; also what are called Dutch tiles for dairies, fish and butter-shop windows, and scales: the cohesion of the soft clay into these forms is caused by immense pressure. Clay, in a dry powdered state, is made into bricks by enormous pressure.

A light, dry needle, if carefully placed on water, will float; and many insects walk upon water: this arises from the cohesion of the fluid, which the weight of the needle or insect is not sufficient to overcome.

At the flatting-mills sheets of tin and lead are rolled out without destroying the cohesion of the atoms.

Gold adheres to steel by being beaten when laid upon its surface.

A piece of thin iron laid upon quicksilver causes the surface of the quicksilver to be repulsed, as seen in its depression around the iron.

Well-polished glass, metal, or marble, appears to the eye perfectly smooth, and it might be thought, upon placing one piece upon another, that their surfaces would touch; but the microscope shews that the smoothness is only comparative, and that very few of the millions of points on the surface actually touch. This roughness prevents the constant adhering of substances, which would otherwise exist on one body touching another; and therefore is one of the wise dispensations of Providence in fitting the world for the use of man.

A common illustration of cohesion without sensible heat is the splitting of a bullet and scraping its surfaces smooth, then pressing them together with a slight twist, and they are found nearly as firm as when first cast. A bullet of a quarter of an inch across its surfaces thus treated would require a force of 100 lbs. to separate them.

Gutta-percha and India-rubber, by being slightly warmed, are formed, by their cohesive powers, into numerous useful articles.

Two pieces of smooth glass, marble, or metal laid upon each other will be found to cohere, from more points touching than in rougher materials; and if oil or water be rubbed on the surfaces, the sticking together will require considerable force to separate them.

Liquids are held together by cohesion, but vary in power, as seen by the different sizes of drops of water, oil, or syrups, when thus measured out.

When solids and liquids stick together, it is called adhesion.

The adhesion of solids to fluids may be felt by placing a large dish on the surface of water, and then raising it equally up.

Most persons know the strength required to lift a piece of ice flat-

ways from water is such, that they generally have to turn it upon its edge to diminish the adhesive power, before being able to remove it.

Adhesion, then, it is plain, adds to the weight of solids. If a piece of smooth copper, having about seven inches of surface, be placed on water, it will be found, over and above the weight of the copper, that 1000 grains will be required to overcome adhesion.

The attraction of the atoms of liquids is sufficiently weak to give way to the attraction of the earth, and thus results the spreading of water and the form of its surface.

Grease repulses water, so that it is difficult to mix them.

An oiled cork put into water is repulsed in every part, and a channel formed around it.

Repulsion is overcome in some cases by melting the parts: the pieces of broken china, glass, furniture, or chimney-piece, are held together by cement; paper is stuck together with paste, and brass and tin utensils with solder. Cements are chosen from their attraction to the material where they are used, and according to their own powers of cohesion. One of the most powerful cements known is marine glue. If a ball of wood be split into quarters, and joined again by this material, then fired from a cannon, it will be found that it has not broken at the parts glued, but at other places.

Chemical, electric, and magnetic attraction and repulsion will be given in another portion of this work.

FORMS OF MATTER IN CRYSTALS.

When matter accumulates or grows into masses, it does not always act as if the attractive power drew it round a centre, but as if it collected it on its sides, and sprouted forth in exact symmetric arrangement, which is called *crystal.* The peculiar forms thus taken by matter are what may be named the geometry of nature, for each part possesses the most regular and correct mathematical shape. Magnetism is supposed to be the mysterious agent in the crystallisation of matter; for each crystal seems to have poles of attraction and repulsion, as cohesion takes place along lines in the matter. Each particular matter that crystallises possesses distinguishing forms, whether it be salt, water, metal, or stone.

Dr. Ehrenberg has proved that to the utmost extent he can reduce a crystal into powder, under a microscope it still is seen to possess the same character as it had when in a mass.

From discoveries in old mines, it would seem that natural crystals arrive at maturity and then decay; as their forms and remains are found, but their principal substance gone.

Snow, seen through a microscope, presents beautifully arranged crystals.

Common salt and sulphuret of lead form similar crystal cubes.

Diamond, the hardest crystal known, is pure charcoal; as a crystal, it and alum have the same form.

The formation of water into ice is effected by crystallisation. A sharp needle-like piece first appears, then another, and another, crossing and joining each other, having fern-like leaves, until a solid substance is formed.

The moisture of a room, when settled on a window-pane, contracts,

from the cold on the outside, and gradually forms beautiful delicate leaf-formed crystals.

Dew falling on a cold surface is transformed into minute crystals called hoar-frost.

A little Glauber's salts being put into a bottle with as much boiling water as will dissolve them, then covered up tightly until cold, a piece of wire stuck through the cover, just to touch the surface, will turn the whole into solid crystals. The effect arises from the air being admitted.

The tree of Diana is a beautiful effect of crystallisation, which is produced by dissolving silver in aqua-fortis, and then pouring the solution of silver into a glass vessel, with a little mercury and distilled water, when a crystallised silver tree arises.

When nature piles up immense buildings of crystal-shaped stone-like magnificent palaces, as on the isle of Staffa, or at the Giant's Causeway in Ireland, they are called basalt. These, as most of nature's works, surpass the conceptions and capabilities of man in beauty and regularity of structure, and might well cause our forefathers, in their wonderment, to imagine that men of gigantic powers and intellect had erected them.

That overwhelming power with which nature, in delicate workmanship, inspires her acts, as exemplified in capillary attraction rending stones, does she instil into the apparently fragile and weak crystallisation of water. The knotted oak, the granite rock, and the towering mountain are shivered, and descend to their lowest level by this power. A slight rent in a tree, a cranny in a rock, a crack in a mountain, becomes occupied with a little water, which the cold of winter crystallises; then with irresistible force these powerful and gigantic bodies are rent in twain; and when heat thaws the combining crystals, the tree, the rock, and the mountain, in fragments, fall into the valleys or plains underneath.

If some metals and earths be rendered fluid, the outside be allowed to cool, and the part that may remain fluid drained off from the middle, it will be seen that the inside is crystallised. The crystallised shape takes up more room than the fluid, because there are more pores in the mass.

It is the crystallisation of water that so beneficially aids the farmer in pulverising the hard and stubborn soil.

At Milan there is a crystal of quartz, about 3 feet and a half long, and 5 feet and a half round, weighing 870lb. Other large crystals are known.

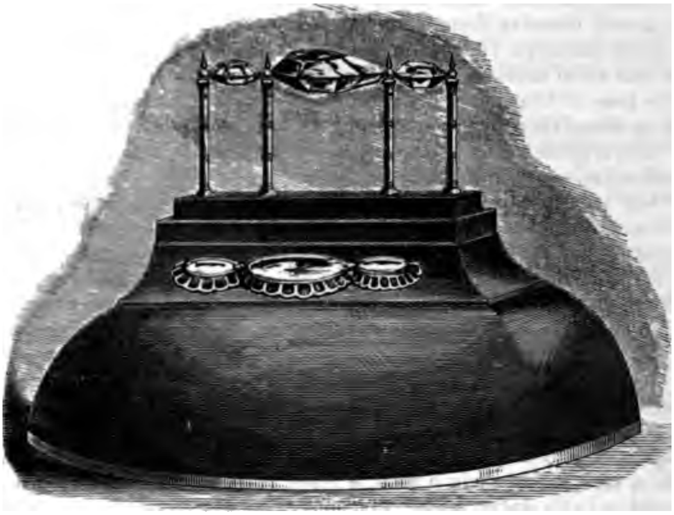
The celebrated Koh-i-noor, or mountain of light, diamond, placed by Her Majesty the Queen of Great Britain in the Great Exhibition of the Industry of all Nations in 1851, weighed 279 9-10ths carats, and is said, before being cut, to have weighed 900 carats. Its estimated value is enormous.

It is a singular property of crystals, that when their primitive form is known, they may be divided into any number of small ones of the same shape.

There seems room to allow a supposition, that nature, in general, shaped all inanimate matter in the form of crystals, but that subsequent violent effects have disarranged the first symmetric forms.

Lamellar Form.—This signifies things lying or formed in thin plates, as we see many stones easily peel off in thin pieces; advantage of which is taken to apply them to the roofs of our houses. A slate taken from a

quarry will be of considerable thickness, and perhaps three feet long, and two feet broad. According to the required thickness of the slate, a chisel is placed at the end, and a smart blow given, when the slate splits into layers ready or use.



Koh-i-noor Diamond.

Fibrous Forms.—When substances are formed of threads, as the nettle, hop, grape, trees, or muscles, they are termed fibrous.

By the processes of man, the texture of things is changed. This is exemplified in iron; in which, when it is first melted from the iron-stone, and poured from the furnace, the atoms are arranged as grains; but when the smith has well hammered it, or when drawn into rods and wires, it is fibrous.

THE PORES OF MATTER.

The more or less visible spaces in substances are called *pores;* and the larger they are, so is a substance said to be more porous than another. Stone, wood, and living animals, are all porous.

Newton thought that the atoms of the most material thing were immensely small, comparatively to the space surrounding each atom; and that if the earth were so compressed as to be without pores, it might possibly not be more than a cubic inch in dimensions.

Sir John Herschell says, a ray of light passing through glass is like a bird threading its way through the mazes of a forest.

Lecturers on science shew the existence of pores in marble and other hard stones, by placing a piece of the material in water, and then withdrawing the surrounding air by means of an air-pump, when bubbles of air are seen to come out of the pores of the stone.

A stone called hydrophane, a kind of agate, is half-transparent; but, after being immersed in water, it absorbs about a sixth of its weight of the water, and becomes a transparent substance.

All bones are porous. On snapping one, we perceive it is full of cells.

The hardest woods are porous in the same manner as we see the cane —that is, a bundle of tubes.

All flesh is porous; and in the living body the pores perform very important functions.

In man 3528 pores have been counted in a square inch of the palm of the hand; and 7,000,000 is estimated as the number in the skin of a person of average size.

A sandstone, abundant near Newcastle-upon-Tyne, is so porous, that it is fashioned into filters for water.

In loaf-sugar the pores formed in crystallisation can be distinctly seen, and as water fills them up, the bulk is not increased.

DENSITY OF BODIES.

Density signifies the closeness or compactness of the grains of bodies. A handful of snow, when lifted from the ground, occupies considerable space; if we squeeze it, the space is much less that it takes up, though every particle be still there—it then is more dense.

By hammering metals, we drive their atoms closer together, and make them more dense, from breaking down the crystals and filling in the interstical spaces.

If tin and copper be mixed to make bronze, the two metals will occupy a fifteenth part less space than when separate, by their forming a denser material.

A pound of salt and a pound of water mixed will not be less in weight, but less in bulk, the brine being denser than the water and salt when separate.

The water of the ocean at a thousand fathoms deep is compressed by the weight resting upon it into a hundredth part less bulk than that on the surface. If a piece of hard wood, such as oak, be sunk this depth for a few hours, it will be found to contain about four-fifths of its weight of water, and be so dense, that the wood will occupy about half its former space, and sink like a piece of iron.

If a bottle of fresh water be sunk in the ocean, the cork will be compressed so as to admit the sea-water; but the cork will resume its former size on being brought up to the surface; still, on tasting the water, it will be found quite salt.

EQUAL BULKS AND SPECIFIC GRAVITY.

A pound of water and a pound of lead weigh the same; but a pint of water and a pint of lead differ much, the lead being about eleven times heavier than the water. Learned men found it useful to mankind to know what proportion equal bulks of different things bore to each other, as a pint of lead to a pint of water: this proportion of weights they call specific gravity. It was necessary, however, to have a standard weight to measure by, and distilled water has been adopted, which, in all places at a certain temperature, and with the barometer at the same height, weighs exactly the same; that is, a cubic foot weighs nearly 1000 ounces. Water is said to be 1; and, for instance, sulphur, which is twice as heavy, 2; marble, 2½; diamond, 3½; tin, 7; iron, 7½; copper, 8½; silver, 10; lead, 11; mercury, 13½; gold, 19; platinum, 23; thus the last-named is the

heaviest metal, being 23 times as heavy as an equal bulk of water. Light substances are measured as being so much less weight than water: thus, beech is seven-tenths less weight; that is, a cubic foot of water weighs 1000 ounces, and a cubic foot of beech nearly 700 ounces. Water weighs about five times as much as cork. Astronomers state that the Sun is only about one quarter as dense as this world; that the planet Mercury is as dense as gold; and that the planet Herschell is not half as dense as water.

HARDNESS OF BODIES.

Hardness is described as that which cannot be easily cut, and will scratch another substance.

Mercury is more dense than steel, but not so hard; thus it is that hardness consists in the force with which the atoms of matter stick together, or the particular manner in which the atoms are arranged or polarised.

Glass will scratch many substances; and flint, diamond, and coke, scratch glass; therefore the three last are harder than glass.

To polish diamonds, requires its own dust: red-lead, a soft substance, polishes glass; and sand cuts and rubs down marble.

Iron can be made hard or soft; steel, when heated to a red heat, and then suddenly cooled, becomes exceedingly hard, and is the valued agent of man in forming tools to aid his efforts and advance civilisation: with them he fashions wood, cuts iron, copper, or brass, and is able to give all the delicate shades of scenery and features of man, in wood or steel, as in the engraver's art; to make dies, whereby he can rapidly form type for the use of printers, emboss paper or buttons, and give to copper, silver, and gold, the legality of a coin of the realm.

When steel is gradually cooled, it is soft, and easily bent or cut.

ELASTICITY.

Elasticity is that power possessed by solid bodies, when they have been pressed, of recovering their former shape or space—allowing their atoms of matter to be removed to a considerable distance, without loss of their attractive force.

If we bend a piece of steel, we must press the atoms of the inner part nearer together, while we separate those on the outside of the curve.

India-rubber, gutta percha, and the muscles of animals, are elastic; but if too much stretched, they lose this power, and remain lengthened ever afterwards.

Glass is the most perfectly elastic substance known; for, if bent during many years by pressure, it will recover its former shape on the removal of the cause. Yet there is a limit, in general, to elasticity, for glass too much bent would break.

The steel small-swords made in this country will bend until the tip of the handle touches the point of the blade. Persons practised in handling these weapons will bend them to this extent, then allow them to spring up into the air, and, on their falling, catch them by the handle.

The Toledo blade shewn at the Great Exhibition in London was bent to a perfect circle, and when released instantly became quite straight.

The watch-spring is an example of elasticity; for, after years of service, it will resume its former position.

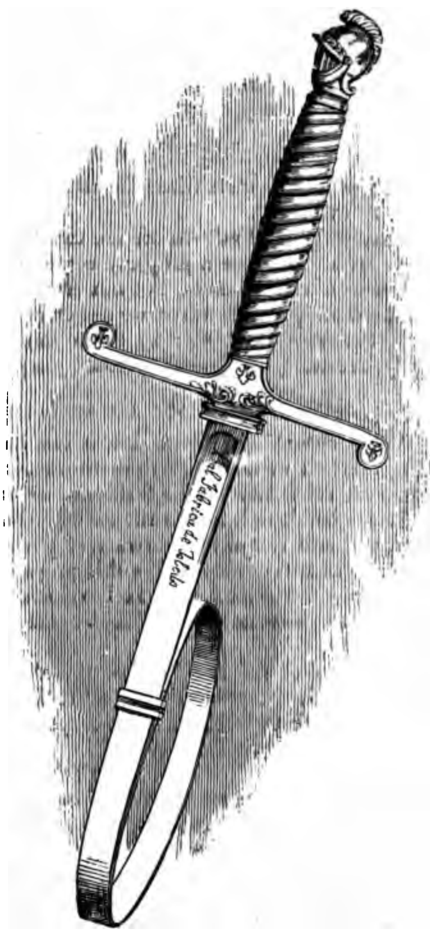
The India-rubber balls of children have great power of elasticity, which partly arises from the air within them.

The tones of the pianoforte and violin are derived from the elasticity of wire and the fibrous parts of animals.

Steel, ivory, wood, hair, and silk, are all elastic, in fact all substances are so more or less.

Water is slightly elastic, but air is particularly so.

Steam, that man has chained to his service in so many important ways, has elasticity to a great degree. Watt, when a boy, sitting over the fire, saw, in the common occurrence of a kettle boiling, the extraordinary power steam possessed, and, like all masterminds, the simple fact of its rushing with fury from the spout, and raising the heavy lid, caused him to conceive its grander application. The apple falling taught Newton a principle of nature's laws; the kettle boiling taught Watt a power for labour's ease.



Toledo Sword-Blade.

To the elasticity of iron we owe the safe conveyance of our brittle goods across the rough pavements; also the luxurious, pleasing swing of the carriages for individuals on the road or the rail.

The elasticity of hair renders the arm-chair, the bed, and the couch, places of ease and rest.

A bladder filled with air gives way to pressure; but on the pressure being removed, recovers its former state; the elasticity of the air is the cause.

An elastic body exerts its force on all sides; but its effect is principally observable where the resistance is weakest. A barrel of a gun is thus equally pressed; but the resistance of the air being the weakest part, the effect is visible at the muzzle. At times, the force of the elastic power produced from the powder will burst the barrel.

Elastic bodies rebound in the same manner as struck or impelled, as shewn in the angle of incidence and reflexion, or of a bell which is struck and sends forth its musical notes.

An elastic body retards motion by repulsion, as seen at railway-stations, where large elastic buffers are placed to stop the carriages.

The elasticity of a silken cord causes it to bear a sudden check better than an iron chain: the one will yield and recover itself, the other must either have strength sufficient to resist, or it will break.

In bringing a ship up by a rope thrown on shore, or fastened to a buoy, the rope would snap, if not eased out until the momentum be destroyed.

BRITTLENESS.

This property exists when the attraction of cohesion between atoms can be easily overcome.

Extremely hard substances are usually brittle, as glass or the edges of tools. It seems to be a property acquired in hardening.

Bar-iron can be bent, but not easily broken; while the pipes of cast-iron, used for gas and water, we see chipped with a slight blow of the hammer. Soft steel is tough; while the fine edges of knives, if tempered too highly, are easily gapped by pieces flying off.

MALLEABILITY.

When any thing is malleable, it can be beaten into thin plates without being cracked or broken. Sometimes heat has to be repeatedly applied before the substance can be fashioned as we desire.

In malleable substances the atoms take up whatever position we give them, and still retain their attractive powers.

Gold, as before shewn, has this property.

By lead being malleable we have many useful utensils; silver, copper, and tin are increased in value for the purposes of man, by possessing this quality.

The arm of the smith, from the malleability of iron, beats the mass into an anchor to grasp the vessel to the bottom of the ocean, or the tiny rod into a tack to fasten down a carpet.

DUCTILITY.

This is the property that some metals have of being drawn into wire.

Tin and lead, although malleable, cannot be so extended; while glass is ductile, but not malleable.

At many humble penny exhibitions the ductility of glass is shewn. A small piece, in a melted state, being taken hold of, it is twisted on to a reel, which is set in motion, and the glass spun at the rate of 1000 yards an hour. It is then taken and cut into lengths, forming beautiful feathers of elastic threads, glittering and transparent; sometimes it is added as tails to birds made of glass.

An ingenious American at Manchester used to draw wire vying with the fineness of human hair; indeed, of such material are now made the wigs of barristers.

Dr. Wollaston drew wire (which we before referred to) of platinum to a most wonderful tenuity, being the one-three-millionth of an inch in diameter.

Platinum, silver, copper, gold, and iron are the bodies that are ductile.

To form wire, a bar of heated iron is made at the end sufficiently pointed to pass through a small hole in a piece of steel; the part at the

outside of the hole is taken hold of with a pair of pincers, and the drawing then proceeds by the workman pulling it through: should thinner or thicker wire be desired, smaller or larger holes are used.

PLIABILITY.

When an object can be bent or placed in any direction without injury, it is called pliant. In ductility the atoms are moved to new situations; but in pliability they retain the same position. The most pliant things are the fibres of animals and vegetables. A bladder is pliant; so is thread, silk, and many other things.

TENACITY.

This signifies the resistance to being pulled asunder; it is the force with which the atoms of any substance cling together. Every thing possesses this quality less or more. The tenacity of metals is tested by the weight they will bear. Steel possesses the quality in the greatest degree; a wire formed of it will support a quantity measuring seven miles and a half (39,600 feet). When only one hundredth of an inch in diameter, a steel wire will bear 134 lb. weight.

If wires be made of different metals, and measure one-tenth of an inch in diameter, the following table shews nearly the number of pounds which will have to be hung upon them before they will break, and thus their tenacity is estimated:

Iron	549 lb.	Gold	150 lb.
Copper	302 ,,	Zinc	109 ,,
Platinum	274 ,,	Tin	34 ,,
Silver	137 ,,	Lead	27 ,,

The paper of a Bank-of-England note will bear, unsized, 36 lb.; but when one grain of size has been added, it will then bear 56 lb.

Count Rumford glued the folds of paper together until formed into a round roll one inch in length and breadth, when he found it would sustain a weight of 30,000 lbs.

Wood.—Teak has a tenacity, comparatively with ash, of 1 lb. less; beech half a pound less than teak; oak half a pound less than beech; and deal 1 lb. less than oak. Deal and silver are about equal in tenacity; while iron is about six times more so than oak.

A writer in the *Mechanic's Magazine* states, if a common sixpenny nail be driven one inch at right angles into the grain of particular woods, the force to overcome the tenacity by which it is held will be in dry oak 507 lb., dry beech 667 lb., dry Christiana deal 187 lb., and in green sycamore 312 lb.

The tenacity of flax renders it useful as cord, twine, rope, and cables; while silk thread, both from this quality and pliancy, is not only valuable in making garments, but also in the delicate instruments used by the philosopher.

It is the tenacity of the muscles that gives grace, motion, activity, and power to man.

When life has ceased, the ligaments and membranes of animals are useful, from having great tenacity; as in the "leathern conveyances," coaches, harness, portmanteaus, shoes, braces, etc.; and, on a large scale,

the bridge across the Maypo, in Chili, which is a suspension-bridge, 123 feet long, formed of twisted ropes of dried bullocks' hides.

The great tenacity of iron has led to many improvements for the comfort, convenience, and prosperity of man. Wire ropes, from their extraordinary power and combining lightness, are gradually being adopted in our maritime industry; iron cables, from their strength, and not having a direct pull on the vessel, but curving in the water from their own weight, which is gradually and gently overcome before there is a positive strain on the vessel, are entirely superseding hempen ones. Those spider-like webs, connecting mountain to mountain, forming a pathway high in air—the suspension-bridges—with vessels passing underneath, owe their value to the tenacity of iron. Two iron ropes, thousands of tons in weight, rising over towers 80 feet in height, stretch over the thundering rapids and fearful chasm of Niagara's falls. On these wires are fixed scantlings, and resting upon them are light planks, forming a safe pathway, 10 feet in width.

The latest and boldest efforts of man's genius, in which iron is made the subservient instrument, is the wonderful tunnel, placed across an arm of the sea, forming a roadway for carriages far above the tallest mast that is borne on the ocean underneath. In this newly-added "wonder of the world" the long-practised areh-formation of such structures is abandoned, and a level defies the elements and strain of man. The stubbornness of strength and firm cohesion of herculean iron stretches from pier to pier, scarcely vibrating or crouching to tons upon tons of moving weight whirled through its sombre interior: we are referring to the Britannia Bridge, which is another brilliant gem added to the civic crown of our indefatigable countrymen. It spans the sea 1513 feet at a height of 102 above the utmost rise of the waves; and of itself weighs 10,570 tons.

MOTION OF PROJECTILES.

When a ball is fired from a cannon, it is affected by two forces: first, the power that drives it forward, and, secondly, the attraction to the earth. The force impelling it forward may be increased, but the power of gravity is never decreased. Thus, whether a ball be driven in a straight line one mile or two miles, it reaches the ground as soon at two miles' distance as at one mile.

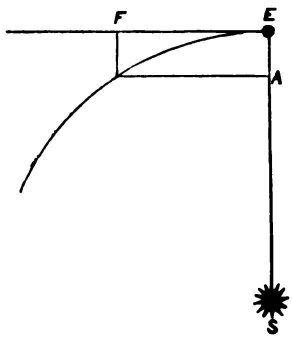
A ball dropped from the mouth of a cannon would reach the ground at the same time, from gravity, as a ball fired the distance of a mile touches the earth, provided it were fired in a line parallel with the earth's surface.

When any thing is forcibly thrown forward, as a bullet, a stone, or an arrow, and the direction given is that of a straight line, it will be seen to have taken a bent or curvilinear direction. If water be forced from the spout of a pump, according to the force given does the water take a short or wide bending motion.

On firing a cannon, this bent motion, from gravity, keeps gradually accumulating, so that the ball is continually approaching the earth, and as more force is applied, the sweep of the curve is enlarged. If the force was great enough to carry the ball twenty miles, the curve would increase, and if fifty miles it would be still larger, and so it would go on until, with increased force, it passed around the earth, and formed a perfect circle.

Were it possible to give a greater force than would send a ball around the earth, it would fly off, and become an independent rolling body.

The motions of the earth and planets seem to arise from the centrifugal force with which they are projected into space being counteracted by the centripetal, thus they have gained that curved motion which they invariably pursue; but from the forces not being at right angles, their path is not a perfect circle.

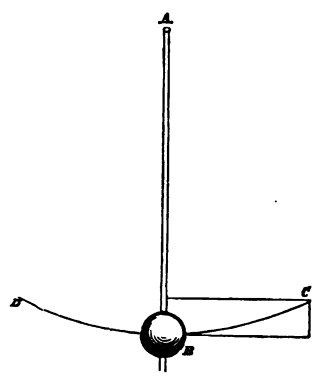


Now suppose S to be the sun and E the earth, that the earth is projected with a force sufficient to send it in a month to F, while the sun's attraction would bring it in that space of time to A, then the two forces acting together on the earth, cause it neither to fly off in a straight line or to fall into the sun; but being controlled by each, continually striving to get away while held fast by attraction, it proceeds in a circular path. The attraction to the sun is called the centripetal force, and the force with which it would go in a straight line the centrifugal.

THE PENDULUM.

A weight fastened to a piece of string attached to a beam, and pulled to one side, then let fall, will rise up on the opposite side and describe a curve. This is from having, when descending, received as much accelerated motion as carries it up the opposite side to an equal height. The momentum will cause it to keep in this motion, until the resistance of the air gradually lessens the curve, and it becomes stationary. This motion of swinging backwards and forwards is called vibration or oscillation.

The pendulum is commonly a thin rod of metal wire, hung from a point A, by a thin metal spring or other contrivance, to allow the pendulum to swing in the proper curve, with a weight at its lower extremity, called the bob B. When the ball is raised to C, it falls, by the force of gravity, like a ball rolling down a slope to the place at which it was at rest B; and as all bodies have their motions as much accelerated whilst descending, as retarded when ascending, it arrives at D, when gravity pulls it back again to B, with accelerated motion sufficient to send it again to C; and thus it would go on for ever, were there neither air nor friction to act as an impediment, and bring it to a rest. From C to D is called its path or arc, and the *amplitude* of an oscillation from C to B is named the descending, and from B to D the ascending, *semi-oscillation*. The *duration* of an oscillation is the time required for passing along its path or arc.



Viewing the motion of the pendulum in the parallelogram of the diagram, it will be seen to act from two forces, the one direction being that of gravity downwards, and the other rectilinear, in the direction B, while the resultant of the two forces is a curve called a *cycloid*.

Whether a pendulum be long or short, its beats are equal if the curve be a cycloid, which differs a little from a circle; and it is this property that constitutes its immense value to man.

The motion of a pendulum is calculated just as precisely as any other simple question of arithmetic. Thus, if the motion of one pendulum takes one second, and another two seconds, the length of the pendulum will be as 1 to 4; that is, the times are multiplied by themselves, as three seconds, the length 9; four seconds, the length 16. Thus, then, the duration of an oscillation being as whole numbers, the length of the pendulum will be as the squares.

In London a pendulum will beat seconds if its length be a little more than 39 inches; for half seconds its length would be nearly 10 inches, thus only about a fourth; a quarter second pendulum nearly 2½ inches, four times less again. Then, for a pendulum to beat two seconds would require one four times as long as a seconds pendulum. This law will be seen to be the same as a falling body increasing four times in two seconds.

A clock is composed of a few wheels which are dragged round by weights attached; the movement of these wheels would be irregular were they not governed by the regular motions of the pendulum; without the pendulum, the hours would not be pointed out, and the clock then of little use. The pendulum is hooked on to a part of the clock, and as it moves it allows a cog of a wheel to pass; this wheel has sixty of those cogs around it; then, as the pendulum swings sixty times in one minute, it just occupies that space of time in passing round; to this wheel a pointer is fixed, which shews on the face of the clock sixty movements of seconds, completing the circle in one minute. The sixty-cogged wheel moves on another wheel at a slower rate, which shews the hours on the dial. Other wheels for other purposes are sometimes added, which are all under the regulation of the pendulum.

The length of the pendulum varies in different places: it is a little longer at Edinburgh than in London; for it is influenced by that universal principle, gravity, as all other bodies are; thus, the thousandth part of an inch in length varies or adjusts its movements to the extent of a second in a day.

At the Equator, the pendulum, from less gravity being there, moves slower; and at the North Pole, from more gravity existing, it moves faster; making a difference of one-fifth of an inch in the length of the pendulum.

We have seen, in a former part of this work, that the heat and cold of the seasons affect iron, and therefore must have an influence on the metal of the rod of the pendulum. To avoid this consequence, serious in many affairs of life, what is called a gridiron pendulum has been invented, which consists of several rods of different metals, so adjusted as to counterbalance the various effects of the seasons.

The length of a pendulum must be measured from *the point of suspension* to *the centre of oscillation*.

The centre of oscillation is that point in a body vibrating by its gravity,

in which, if the whole mass be collected, it will perform its vibrations in the same time, and with the same angular velocity as the whole body about the same point or axis of suspension. In the pendulum it exactly agrees with *the centre of percussion.*

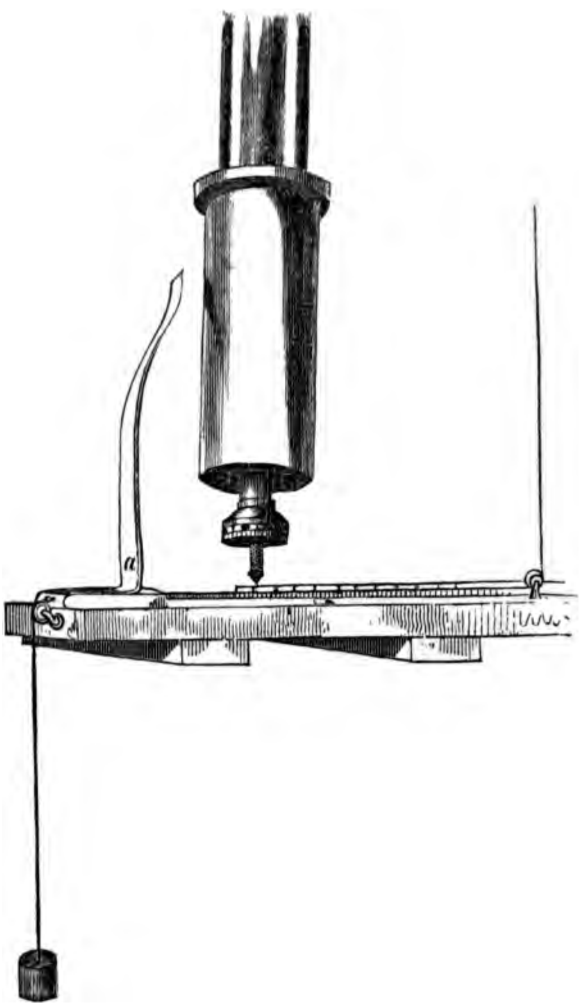
The invention of the long pendulum is claimed by a London artist, named Richard Harris, who applied it to a clock in 1611, which is seventeen years before the time that Galileo states he directed one to be made.

When the Royal Exchange of London was, in 1844, completed, the "merchant princes" advertised for a clock "so true in its continuous action, that the first blow of each hour should be accurate to a second of time; and that as a protection against varying temperatures, the pendulum should be a compensating one." Professor Airy, the Astronomer Royal, who had distinguished himself in this branch of mechanism, as well as in explaining and exploring the wondrous gigantic mechanism of the heavens, was solicited to superintend its arrangement, which he did; and the able chronometer-maker, Dent, was selected for its construction, entering upon his duty as a labour of love. The portion of this perfect piece of mechanism we are called upon in this division of our work to notice is the pendulum. We must state, however, first, that part of the machinery is engaged in raising a ball at certain intervals (20 seconds), which ball, falling through a small arc of about 40°, by its gravity causes an impulse to be given to the pendulum; and it follows that, so long as this ball is raised by the larger mechanism, the impulse to the pendulum may be fairly termed equal at all times, and not subjected to the variation of force to which public clocks are usually subjected from the varying friction, change in the fluidity of the oil by temperature, or the effect of the wind on the hands of the four faces, which are nine feet in diameter. Thus, then, it will be observed, that the impulse is given to the pendulum by the falling of this ball, or, in other words, by gravity, and not by the clock weight, as is the case in the ordinary construction.

The compensation-pendulum is, as we have stated, to correct the varying temperatures to which a clock must of necessity, in an exposed situation, be subjected. The compensation is effected by the equivalent contraction and expansion of a system of combined rods of zinc and steel: the centre rod is of steel, the whole length of the pendulum; and at the bottom of the pendulum, as shewn in the figure, is placed the zinc column. It is evident, that if the rod lengthens downwards by an increase of heat, the column of zinc *standing on the nut,* perfectly free of the steel rod, will expand upwards. On the top of the column of zinc is fixed a metal cap *d,* into which is firmly fixed two steel rods, and at the bottom of them the pendulum-bob, from which it follows that the bob hangs by means of these two rods from the top of the zinc column, and quite independent of the centre rod. The zinc column, expanding upwards by an increase of temperature, raises the pendulum-bob, while at the same time the rod lengthens by the increase of heat. The zinc column is made shorter than the steel rod, which arises from zinc expanding and contracting more than steel, for equal increase and decrease of heat.

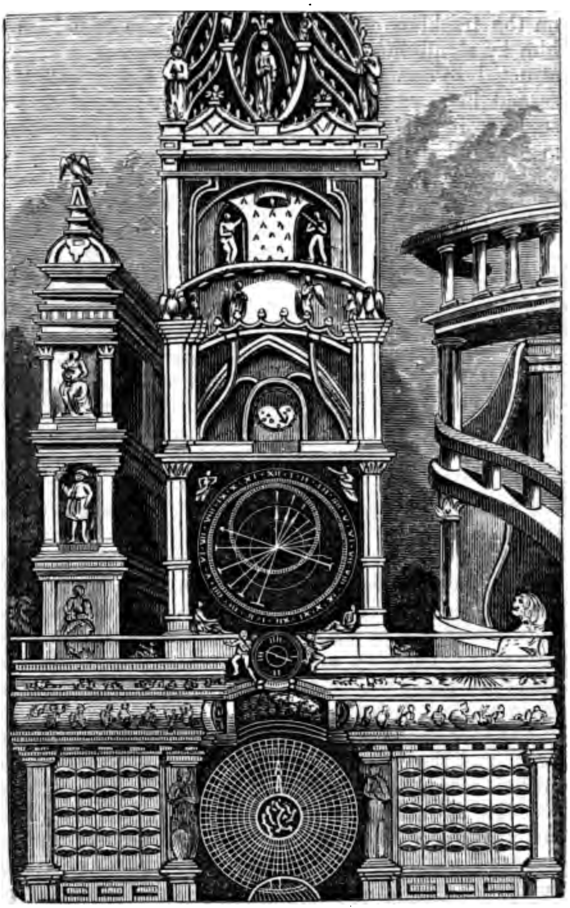
The clock being required to be set to within a fraction of a second, it was found that if the pendulum was stopped by hand, it would be next to impossible to put so large and heavy a mass as nearly four cwt. in motion

to such a small portion of time. Again, the difficulty of setting it, to vibrate in the same plane, as well as to give the usual extent of arc of vibration, rendered it impossible to accomplish the regulation, or, more properly, the "setting it," to the required nicety. Mr. Airy at once suggested an ingenious and simple mode of overcoming the difficulty. He directed the clock to be started at a very small losing rate, and then that a spring, shewn at *a*, should be brought against the pendulum, by means of a line, in the clock-room, so that it might be made to touch the pen-



dulum slightly, and cause a corresponding gain in the clock, which it does to the minutest fraction of a second. In fact, it affords the means of putting the beats of a great turret clock and a comparing chronometer in coincidence.

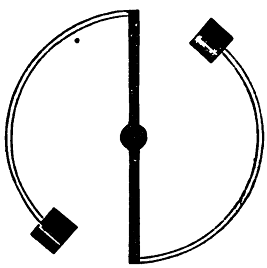
The regulation of the pendulum, to bring it nearly to mean time, is effected by a screw at the bottom, taking care that the rate of going is always a *losing* one. The screw is not afterwards to be moved; but for the regulation of any small portions of time there are weights prepared to place on each side of the top pendulum-bob. By this plan, there is no occasion, at any time, to stop the pendulum; and the smaller weights will correct with certainty periods of less than a tenth of a second daily. Should the clock gain, the weights are, of course, removed.



The most remarkable piece of mechanism worked by the movements of a clock was that at Strasburg. The plate exhibited a celestial globe, with the motions of the sun, moon, earth, and planets, the phases of the moon, and a perpetual almanac on which the day of the month was pointed out by a statue; the first quarter of the hour was struck by a child with an apple, the second by a boy with an arrow, the third by a man in his prime with a staff, and the last quarter by an old man with a crutch. The hour was struck by an angel, who opened a door, and saluted the Virgin Mary; another angel turned an hour-glass, on the completion of the hour. A golden cock, at every hour, flapped its wings, and, stretching its neck, crowed.

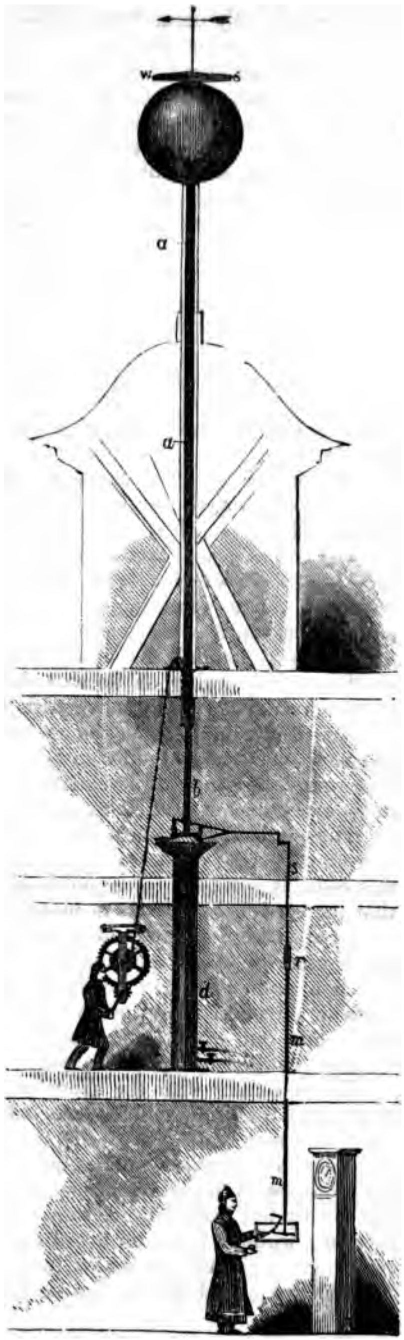
In that useful companion to man, a watch, the weights of a clock are substituted by a spring. Now a spring acting in all positions enables the little instrument to perform its duties regularly, in whatever way it may be hung, laid, or carried. The fusee on which the chain is wound is a varied lever, so that, as the action of the main-spring is lessened by unwinding, it acts in such proportion that a constant quantity of power is in existence to regulate the two forces. The balance-wheel is the representative of the pendulum; but to compensate for the oscillation produced by gravity on the pendulum, the watch has a delicate spiral spring to which the balance-wheel is attached: the elasticity of this spring is such that it bends and unbends with uniformity, and equalises the motion of the balance-wheel.

The *chronometer*, on whose dial the mariner gazes to know his position on the trackless ocean, which warns him of hidden dangers, and delights him by signifying that his haven is near, is a large watch, carefully constructed, so accurate in its movements that it will rarely vary more than a second in a year of incessant industry: were its truth to deviate a few seconds, it might cause a wreck of man's ocean home, the links of commerce, and death to those confiding in its guidance. The chronometer, however, differs from the common watch in the balance-wheel not being an entire circle, but more as if an S was intended, only the middle part, connecting the top and bottom segments of circles, is a straight line; at the end of each of these parts of the circle is placed a small ball. This balance is composed of different metals soldered together, to prevent the effects of heat or cold on it. There are other contrivances or improvements on common watches in the chronometers which it would be difficult to explain. England is celebrated for their manufacture, as it is in all things where science aids the useful, and thus the commercial and war fleets of the world are indebted for safety to our ingenuity.



The Time-ball at Greenwich is that exact monitor by which our commercial navy on the Thames regulate their time-keepers. At five minutes to one o'clock every day the ball is hoisted half-mast high; it is afterwards drawn to the top. Exactly at one o'clock, mean time at Greenwich, it descends. Thus, by watching it two or three days, the errors of a chronometer are easily detected, and the mean time at all other places ascertained when the longitudes are known.

The accompanying illustration exhibits a section of the first, second, and third floors, in which the apparatus is placed, which may be said to consist of a hoist for raising the ball, a trigger and discharging gear for its liberation, and a clock regulated by observation, for giving the required moment of time: *a a* is the supporting shaft bearing the ball on its top and terminating below at *b* in a piston, which works in an air-cylinder *d*, and by which the too sudden descent of the ball is prevented; *m*, *m*, *r*, *s*, is a combination of rods and levers connected with the discharging trigger.



In the second floor is a windlass, having a chain passing over a pulley, by which the ball is raised to the top of the pole.

On the first floor is the discharging trigger, which is let go the moment it is one o'clock; as the ball is some seconds in falling, the first movement of it downward is the exact time.

A time-ball has also been fixed on the top of the Electric Telegraph Office in West Strand, London, which falls simultaneously with that at Greenwich. The plan adopted, both for dropping the ball and for the transmission of signals, is automatic, the galvanic circuit being completed by certain pins or studs affixed to the train of wheels of Mr. Shepherd's electro-magnetic clock at Greenwich. Some of these wheels carry one or more pins, according to the signals required. At one o'clock the circuit is completed, and an electro-magnet, placed near the discharging-rod of the ball apparatus, at this instant becomes a powerful magnet, and draws towards itself a piece of iron, which, till this time, supports the lever or trigger of the discharging-rod, and thus relieves the supporting-shaft with the ball at its top. In the new method the spring at the trigger is replaced by a piece of iron, and the observer, seen in the first floor, is replaced by an electro-magnet, which unerringly discharges the trigger, as above stated, and causes the hour of one o'clock to be announced by the descent of the balls. In a similar manner this clock transmits signals twice a day to several railway stations.

The universality of the railway system throughout the length and breadth of the land has rendered it a necessity to be guided in all parts of the kingdom by the same time, otherwise serious accidents

might continually occur from collision of trains, and therefore Greenwich time, announced by the time-ball, is that now regulating the clocks of the railways all over Great Britain : certainly some denizens of antiquated cathedral towns, where the learned are lost in contemplation of the darkness of the past, are reluctant to participate in the brilliancy of the present, and reject the progression of time; while the alarmed matrons of western cities see a doubt as to the important circumstance of dating the birth of their babies, who may be brought on to the stage of the world a few minutes before the hour of midnight in their native cities.

ON MOTION AND FORCES.

MOTION signifies a change of place; every thing is either at rest or in motion.

Motion exists in the heavens and the earth; by it we have day and night, heat and cold, rain and sunshine, tides and tempests, life and sound; in fact, without it, all would be silence, coldness, and death.

When the heated iron swells, it is the motion of heat acting on the atoms that compose its bulk. When the human voice is heard, it is the motion of the air vibrating on our ears.

Various kinds of motions are thus distinguished:—

Common Motion is that in which we participate with other objects; thus, on the earth's turning on its axis daily, and revolving round the sun annually, we unconsciously move with it; so calmly majestic is this motion, that few think they are on the surface of a body twirling round at a rate of nearly one thousand miles an hour, and advancing in a circle, at the same time round the sun with a velocity of 68,040 miles every hour, or nineteen miles every second of their existence.

Thus it is that, when motion is easy and regular, we are insensible of it from partaking of that of the object in or on which we move, and from this cause it was long before philosophers could convince the popular mind that the earth actually was in motion.

In a carriage moving along a smooth road, and the blinds down a person is unaware of his actual progress.

In a cabin of a ship, when sailing at a quick rate, the motion of progress or direction is unknown ; the waves are heard flapping against the ship's side, but whether the vessel be moving slowly, quickly, or at all, cannot be stated by the passenger.

When sailing with the shore in view, the lighthouses, churches, and trees seem receding, and those in advance coming forward, as if to welcome our visit.

When a ship at sea sails as quickly as another, to the persons on board the ships seems to make no progress; if one ship passes another, the people in the ship left behind think they are at rest, and the other vessel only in motion ; while to those on board the swifter vessel the other appears to be receding. This all shews how insensible we are to the motion in which we participate, and how the senses may be deceived thereby.

When passing through a tunnel on a railway, or shut up in a carriage, we are unconscious of a change of place. On moving swiftly in a railway-carriage, and looking steadily at an object, the landscape seems as if it was reeling round in an eddy, and the horseman on the road looks as if he and his galloping steed strove in vain to progress, and to be whirling swiftly backwards. Thus sight is deceived, and *seeing* is *not* believing.

Relative Motion means a body that is in motion with regard to one thing and at rest with regard to another. Thus, if a man be on a barge sailing down the river, and walks from the stem to the stern at the same rate as the tide is carrying the barge, he would be in motion relatively to the barge, but at rest as respects the bottom of the river or its banks.

Absolute Motion applies to the heavenly bodies, including our own earth: it is the movement from one part of space to another. By judging the sun to be a fixed body, the motion of the earth is taken relatively to it; but the sun, says Sir John Herschell, has a motion independent of that on its own axis of 422,000 miles per day, carrying with it the planets and comets.

Peters states that the sun, attended by all its planets, satellites, and comets, is sweeping through space with a velocity which causes it to pass over a distance equal to 33,350,000 miles in every year.

Maedler, after a profound examination, has arrived at the conclusion that the central sun in our astral system is Alcyone, the principal star in the group of the Pleiades, and is the centre of gravity, around which the sun and stars composing our system are all revolving. The distance of our sun from Alcyone is so great that light requires 537 years to pass from the one to the other, and that it will take 18,000,000 years for our sun, with all its planets, satellites, and comets, to complete one revolution around its grand centre.

The glorious discoveries in astronomical science by Copernicus, Kepler, Newton, and the Herschells, when first announced were treated with doubt or neglect, but finally established as incontrovertible truths; science being but in its infancy, we doubt not in a short time that the above penetration of the mysteries of the Divine Architect will not only be further elucidated, but fully corroborated.

Rapid Motion is such as light, electricity, or lightning.

Light travels about 192,000 miles in a second, and therefore would pass around the globe eight times during that small portion of man's mode of measuring periods.

Light from a nebula, that may be seen by the naked eye, travelling at a rate of 12,000,000 of miles in a minute, takes 60,000 years to accomplish its journey to our globe.

Electricity, as in the telegraph, speeds at the rate of 285,000 miles in a second; hence would perform its journey nearly twelve times around the earth in that fraction of time.

Slow Motion is such as the growth of plants and animals, the motion of the hour-pointer on the clock, or the shadow on a sun-dial.

Rectilinear Motion means that which is in a *straight* line. Thus, a body that moves in a direct line to a certain place is said to have a rectilinear motion. A stone dropped to the ground is an instance.

Curvilinear is when a body has a bent, arched *Motion;* as when water is pumped from a fire-engine; a stone cast slantingly, for then it does not go straight, but is continually changing its direction.

Uniform Motion is when a body passes over a certain space in a certain time, and continues to do so with regularity. The seconds, minute, and hour pointers of the clock do so in the particular parts of which their uses are adapted.

Accelerated Motion is when a body increases in rapidity as it progresses. A stone down a mountain increases in speed as it advances towards the bottom; a railway-train down an inclined plain will start slowly, but rush with impetuous velocity as it gains the bottom of the incline.

Retarded Motion is when a moving body becomes slower and slower in action as it advances. A ball cast along a pavement illustrates this; or a stone thrown upwards into the air moves less and less quickly until it stops, and then commences its descent.

INERTIA OR INACTIVITY OF MATTER.

All matter is said to resist a change of state, from rest to motion, or from motion to rest; and this resistance of a body at rest to being put in motion, or of a body in motion to be stopped and rest, is said to be the inertia of matter. It is sometimes called the *obstinacy*, *sluggishness*, *stubbornness*, and recently, more correctly, the *persistence* of matter to remain as it is, and the necessity of *force* to produce a change of any kind, either as to its motion or direction.

In a railway-carriage, on the commencement of motion, a jerk or tug is given, when every one is thrown backward; this arises from the body being at rest resisting the commencement of motion, which is communicated suddenly; and if the train be quickly stopped, the body, which then has gained the motion of the carriage, is still advancing, and thus pitched forward.

When standing in a boat which is shoved from the shore, the feet are dragged away with the boat, but, the body being at rest, it falls towards the shore, resisting the motion; when the boat suddenly stops, the passengers are thrown forward, from the same reason as given in the case of the carriage.

When a steamboat has a great many persons on board, and runs against any thing, the swaying motion thus given by a large number of people checked of motion is sufficient to cause serious accidents, as the boat might be upset.

Dr. Arnott relates, that a young man unpractised in driving, having run his curricle against a heavy carriage on the road, foolishly and dishonestly excused his awkwardness in a way which led to his father's prosecuting the coachman for furious driving. The youth and his servant both gave evidence that the shock of the carriage threw them over their horses' heads, and thus they lost their cause, by unwittingly proving that the faulty velocity was their own.

Accidents have occurred on railways from the engines giving leaps, the fore part rising most when the breaks have been applied, which at the inquests do not seem to have been properly accounted for: it is admitted that the speed was great when the breaks were applied, hence the suddenly checking of the fore part of the train or of the engine would cause the after part to abut against that preceding it, which also striking the engine, would, in case of the force of the blow being below the centre of motion of the engine, cause it to leap as described.

A conductor jumping from an omnibus in motion, as soon as he touches the ground, runs forward a few steps, because his body, having the forward motion of the vehicle, it must be continued until he gets clear of it, otherwise he would fall to the ground.

A person may jump from a moderately high cart or carriage at rest without injury; but when they are in motion, according to the velocity, is he dashed on the ground. Thus, a person may step out of a railway-carriage at rest without injury, but when in rapid motion it would be almost sure death; the velocity of the carriage being conveyed to the body, it meets the earth with all that force.

The Irishman who said the fall did not hurt him, it was the stopping it that did the injury, spoke philosophically; it was the resistance of matter to a change of its state.

It is by this participation of motion that all things remain in what we call a state of rest, as man on the earth, the furniture of our houses, the buildings and pillars we raise, for all things partake of the motion of the earth.

A weight dropped from the main truck of the mast of a vessel sailing swiftly falls in a line with the deck, the same as if it had been dropped from a housetop, because the person and the weight itself have the motion of the ship.

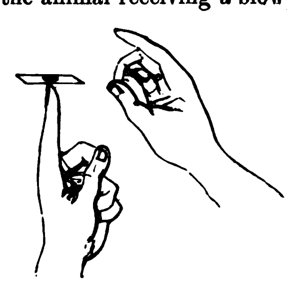
The boys who beg at the sides of the running coaches understand this philosophical truth practically, for they dart forward to catch the falling halfpence.

To common motion, it is evident, we are insensible; for when in the cabin of a steam-vessel, we cannot tell, from the objects around, where we are going, or at what rate, or whether we are in motion at all. When the sea is smooth, we may walk to or fro, toss a ball from one end to another, write, read, hand wine, or build a house of cards, as if no motion whatever was taking place.

A man may balance a pole on his chin, and walk about with it, the pole remaining steady, because it partakes of the man's motion.

At Astley's, when standing on the back of a galloping horse, the performer will leap over a garter, or through a hoop. In doing so he only leaps up; for, having already the motion of the horse, he goes forward at the same rate as when on its back: were he to add force to this progressive motion, he would leap over the horse's head.

A person sitting carelessly on a horse, and the animal receiving a blow from which it starts suddenly forward, the rider finds himself on terra firma. This arises from the stubbornness of matter to motion, as in this case, that of the equestrian's body.



If a card be balanced on the tip of a finger, then a coin placed on the card, and the latter receive a smart tap, it will fly away, leaving the coin on the finger-end.

Motion is divided into what are called laws, which are three in number.

LAWS OF MOTION.—LAW I.

The first law of motion was discovered by Kepler, the great predecessor of Newton : it is, "That a body will continue in a state of rest, or of uniform motion in a straight line, until it is compelled to change its state from some form impressed upon it." This means, that a body will continue at rest if force be not used to move it ; and that, when moved, every thing would move straight forward and uniformly, if some power was not applied to bend its motion, or stop it entirely.

A body once set in motion would never stop, did not friction, gravity, or resistance of the air oppose it, and restore it to rest.

A stone flung into the air would move on for ever, if the air did not resist its progress, and gravity bring it down to the earth.

A marble rolled amongst grass, on a gravel path, a smooth pavement, or on ice, has a proportionate progress ; moving an immense distance on smooth ice to what it would on grass, because it has less friction to overcome on the ice than the grass.

Motion resists rest, which is seen where there are no obstacles, as in the planets ; and, as every thing is in motion with the earth, we may justly say there is no such thing as absolute rest, though we have relative rest as well as relative motion.

Were there no such thing as friction, gravity, and resistance of atmosphere, there would be no hindrance to a thing once put in motion so continuing for ever, and thus having perpetual motion.

LAW II.

The second law of motion is due to that British luminary, Newton : it is, "That every change of motion is in proportion to the force that makes the change, and in the direction of that straight line in which the force is impressed."

A football may receive a kick, sending it in a direct line ; but another person gives it a blow which turns it out of its path, and changes its direction.

According to the charge put into a gun, so will be the distance to which a bullet will be driven.

When the bullet is discharged, gravity acts upon and pulls it to the earth, and thus its direction is changed from a straight line.

This law, as will be afterwards exemplified, is important in navigating ships ; for, the motion being made in the direction in which the force is impressed, a sailor can tell in which direction the winds and currents will take him. Boys know that when sailing their tiny boats, if the stream runs in one direction, and the wind blows across the little brook, the liliputian bark neither goes direct down with the tide nor direct across with the wind, but takes a slanting direction to the opposite shore. This slanting direction, or diagonal line, as it is called, can always be calculated, so that a sailor can say exactly to what part he will proceed with these forces acting upon his ship.

LAW III.

To Galileo we owe this law, which is, "That action and re-action are always equal and in opposite directions."

Thus, if an anvil be struck by a hammer, it resists with a force equal to the blow.

When a tennis-ball is struck against a wall, the wall resists with equal force, and drives it back again.

A horse dragging a load is drawn back, equal to the weight of the load, as he draws it forward. That is, if a horse's strength be equal to one ton, and a weight of one ton be placed for him to draw, just as much weight will hold him back as he has strength; but if his strength be two tons he loses one ton of it by the weight, and with his other ton of strength drags onward the weight; then, again, if he only progresses two miles an hour with the one ton, exerting himself equally without the weight, he would advance four miles an hour.

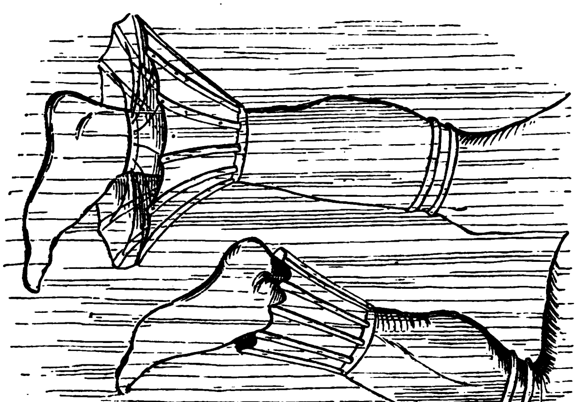
If a man in a boat pull another boat towards him, and the boats be of equal weight, they will meet exactly half-way.

It is by the resistance of the water against the oar that the boat is moved on its journey.

A bird flying strikes the air with its wings, if with force equal to its weight, it keeps itself in its position; if with less force it sinks, and if with greater force it rises.

If we step on a quicksand we sink, because there is no equal resistance to our pressure; but on the earth the resistance is equal to our pressure, and therefore we feel safe and steady.

A very ingenious contrivance has been invented, which consists of a kind of stocking to fit on the ancle when swimming: on drawing the leg up, it lies flat against the side of the foot, offering little resistance to the



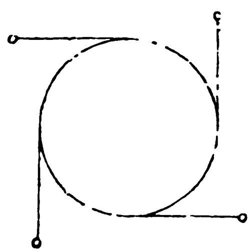
water, but when the leg is thrust from the body in the act of swimming, it opens like an umbrella, and consequently aids, by the surface exposed to resist the water, the progress of the swimmer.

CENTRIFUGAL FORCE.

It has been seen that the tendency of all matter in motion is to move in a straight line, and that when it does not do so, some power acts upon it and prevents it. The earth has a motion nearly in a circle around the sun; its tendency is to fly off in a straight line, but is prevented doing so by the attraction of the sun, which is in opposition to the inertia or persistence of all matter. This trying to get away is called the *centrifugal* or centre-flying force.

When we twirl a wet mop rapidly round, the water flies off in a straight line from the different points, but bends and falls to the ground from gravity.

A plummet fastened to a string, and whirled round, makes a constant effort to move in a straight line; but from being held to a centre every movement is bent: cut the string, and then it would dart off in a direct line, which is a tangent to its circular motion.



When a dog comes out of water, it shakes itself, and the water flies off in direct lines. The mud on a carriage-wheel flies away in a straight line from different parts.

When corn is ground, it is dropped into the middle part and between two round stones whirling round, but flies off from that part, and arrives at the edge of the stones as flour.

If a top be spinning, and a little water be dropped upon it, the water is whirled to a distance from the plaything.

A man bound to a moving wheel, with his head towards the edges, dies from apoplexy: the blood striving to fly away fills the brain, so as to cause death.

There have been many lamentable instances of persons being on the upright wand of a windmill, which, accidentally set in motion, has caused death.

Medical men strongly denounced the old-fashioned practice of rocking children in cradles, as from the position of the raised head the blood is forced by the motion to that part, and hence is injurious. The swing is more heathful, because the head has not so much motion as the feet and lower part of the body, and the blood is rather decreased from the head by the motion than otherwise.

The potter makes use of centrifugal force to aid in his useful handicraft. A piece of clay is placed on a rapidly-moving flat wheel, and the clay flattens out in endeavouring to move from the centre; with the aid of his fingers and a little tool, he, with astonishing dexterity, turns cup after cup and saucer after saucer.

Our common window-glass is also by this force manufactured into sheets. A mass of molten glass on an iron rod is made to turn rapidly round; it spreads out on the table into a thin round plate, from which afterwards are cut different-sized panes.

If a pail with water be whirled about, the water rises at the sides of the vessel, leaving a hollow in the centre, the water trying to escape.

Water poured on a turning grindstone will be seen to rise up, and as motion increases, fly off.

CENTRIPETAL FORCE.

This means centre-seeking force. It is the power that draws inward, towards the centre of a circle.

The sun is the centripetal force which balances the centrifugal motion of the earth, and thus keeps it in its orbit. Were the centripetal force to predominate, the earth and sun would continually approach each other till they became one mass; on the contrary, had the centrifugal force predominated, our sun by this time would have been but little use to us from its great distance.

If a stone be placed in a sling, and whirled round while the cord is held, that is the centripetal force; but when one of the cords is let loose, the stone darts off in a straight direction, and that is centrifugal force.

It was formerly a favourite performance of circus people to place a glass of water in a hoop and swing it round in all directions, then restore it to rest without spilling a drop: a quarter of a century has outlived this as a subject of wonder and applause to a miscellaneous assembly, for philosophy has been actively scattering her seeds among young and old; the cunning man has been found to be only practising a simple illustration of nature's laws.

When water is poured into a funnel in a slanting direction, it whirls round the sides, leaving a space in the middle, the water having a tendency to fly off.

A body of water suddenly stopped in its onward course by a rock or land, turns round and forms an eddy or whirlpool.

When winds meet with opposing winds, they turn round like the water, and suck up leaves and dust into their eddies.

A horseman on turning a sharp corner leans inwards, that he may overcome the centrifugal force.

At exhibitions of horsemanship, while riding round the circle, both man and horse lean toward the centre, and the faster they go the more they incline inward, that their centripetal position may equalise their centrifugal force.

In skating, a person in describing a circle leans inwards in such a manner that without motion he would fall; the motion prevents his downward progress, and he thus wheels about in graceful action.

Dr. Arnott gives the following excellent illustrations:—In skating with great velocity, this leaning inwards at the turnings becomes very remarkable, and gives occasion to the fine variety of attitudes displayed by the expert; and if a skater in running, finds his body incline to one side, and the centrifugal force of the body, refusing as it were to follow in the curve, restores the perpendicularity. Skating becomes to the intelligent man an intellectual, as well as a sensitive or bodily treat, from its exemplifying so pleasingly the laws of motion. The last example explains also why a hoop rolled along the ground goes so long without falling; if it incline to one side, threatening to fall, by that very circumstance its course is bent to that side, and, like the skater who bends, it rises again; the bending of its course to either side thus brings its supporting

base again under it. A coin dropped on the table or floor often exhibits the same phenomenon. It is said to run and hide itself in the corner. Before falling, if not obstructed, it generally makes several revolutions in a small circle. The reason also why a spinning-top stands will be understood here. While the top is perfectly upright, its point, being immediately under its centre, supports it steadily, and has no tendency to move from the place ; but if the top incline at all, the side of the point, instead of the very point, comes in contact with the floor, and is as a little wheel or roller, advancing quickly and describing a curve somewhat as a skater does, until it comes directly under the body of the top as before. It thus appears that the very fact of the top inclining causes the point to shift its place until it comes again immediately under the centre of the top. It is remarkable that even in philosophical treatises of authority the standing of the top is still vaguely attributed to *centrifugal force,* and hence many persons believe, that a top spinning in a weighing-scale would be found lighter than when at rest.

THE AXIS.

The *axis* of a body is the line about which revolving bodies move, but which remains itself at rest.

In what has preceded, it has been shewn that any thing a distance from the axis of a turning body, as water on a grindstone, has a tendency to fly off. On the earth, the ocean is sixteen miles higher at the equator than at the poles, which are the axes ; now, this is the effect of centrifugal force, while the water remaining there, and not flying off, is the effect of gravity, or centrifugal force. So beautifully does the Divine Creator adapt the mechanism of the earth, that a proper equality exists of this repulsive and attractive property; were the motion of the earth quickened, then gravity would be overcome and centrifugal force prevail; and did not centrifugal force exist, the earth would be dragged to the sun—thus, in either case, destruction to us would ensue.

The greater the distance from the axis, the greater the velocity of motion. A small wheel turned at the same rate as a large one has not near the same motion, and their increase of distance increases the velocity; nay, this force may be so increased as to be more powerful than the cohesion of the matter: instances of which sometimes occur in machinery, where a metal or stone wheel has flown into pieces, scattering destruction around.

In the action of a windmill, the axis is the centre part on which the vanes are fixed. The parts furthest from the axis have the greatest velocity, as they have to move over a much larger space than those near to the axis, in the same space of time.

The motions of the planets, by the action of centrifugal and centripetal forces, are, according to a certain ratio, regulated by their masses and distances from the sun. When a body is increased in mass, and its distance from the centre and velocity remain the same, then the centrifugal force is increased in proportion ; the same is the result if it remain in mass and velocity as before, and the distance from the centre be increased. If our earth were to perform twice the revolutions it does in the same

period of time, the centrifugal force would be increased four times; and if its revolutions were increased to three times as many as now, its centrifugal force would be nine times as great; and so on, multiplying the increase of speed by itself, the result is the increase of the force.

MOTION ACCORDING TO FORCE.

To put a body in motion requires force, and according to the *quantity of matter*, so is *the quantity of motion* required to give different bulks the *same velocity*.

If a quoit of one pound be pitched ten yards, it will require double the force to pitch one weighing two pounds the same distance.

In unloading a cargo of cheeses, the men stand at certain distances, pitching them along. If some weigh 100 lb. and others 10 lb. each, and the distance with the small ones be ten times greater than that with the larger ones; the 10 lb. cheeses have ten times the velocity given to them that the large ones have.

If a ball be pitched easily at a mark five yards distant, its motion is comparatively slow to what it would be if the hand were drawn back, and the ball driven with the utmost force of the person; thus, then, *according to the force is the motion produced.*

To move, then, a heavy body as quickly as a lighter one requires increase of force.

If a musket-ball and a cannon-ball have to move over the same space of ground at the same time, the atoms of matter in the cannon-ball will require pounds of gunpowder to the ounce required to move the comparatively few atoms of the musket-ball.

The same force applied to different quantities of matter moves them

in proportion to their weight. Thus, a man in a racing skiff passes over a great space with rapidity. The same man, exerting the same amount of strength, and towing a barge, moves more slowly; and when tugging at a ship with all his might, his progress becomes almost disheartening.

VELOCITY.

Intensity, not quantity, of motion is meant by velocity. Velocity, or swiftness, is measured by the time employed in moving over a certain space. Thus, if a cannon-ball move about 1000 feet in a second, and a railway-engine about 100 feet in the same time, the ball has ten times the velocity of the engine.

It has been shewn that every atom of matter is almost equally attracted or pulled to the earth; and yet, if a shilling and a feather be dropped, the difference in their velocities or swiftness in reaching the ground is considerable: but this arises from the atoms of which the feather is composed being more expanded, and the resistance of the air causing it to fall slowly; take away the air, as can be done by an air-pump, the feather and coin will fall with almost equal rapidity.

If a sovereign was beaten out into a thin leaf, the resistance of the air would prevent it reaching the ground with the same velocity as when in the form of a coin.

Thus, velocity is retarded or diminished by the air of the atmosphere.

MOMENTUM.

This is the quantity of motion that a body has accumulated within itself, and is in proportion to its velocity and mass of matter. The motion given by force can be communicated to another body in quantity equal to that which it possesses.

Thus, a person may roll a cannon-ball from his hand against a thick piece of timber, and the momentum of force not being much, the timber receives little injury. If the ball be fired at a distance, it will bruise and splinter the wood; but if fired at a short distance, it will pass through it.

An empty jolly-boat drifting with the tide against a person's leg hanging over a quay would bruise it; but if the boat were heavily laden, and men pulling it swiftly along, the leg would be nipped off.

A ship dropping down a river with the tide will get aground on a sand-bank; but with her sails set, and a strong wind, she would shake her timbers, and probably her masts fall overboard.

The momentum we give a hammer in driving a nail is small to that we use in fixing a stake.

A great velocity given to a small body may equal in effect a less velocity given to a large one. Thus, a battering-ram does no more than a cannon-ball. A cannon-ball 28 lb. weight, passing at a rate of 1072 feet per second, would equal a battering-ram of 15,000 lb. weight moved at two feet per second. This is calculated by multiplying the weight by the space passed over by the ram, equal to 30,000; divide this by the weight of the ball, 28, and the velocity necessary for the ball is thus known,—nearly 1072 feet per second.

A light body with increased momentum will strike as powerfully as a larger having less momentum or velocity: thus a ball 3 lb. weight with a

momentum of 300 feet per second will strike with as much force as a 30 lb. ball driven at a rate of 30 feet per second.

Velocity being attained by distance of the fall is the reason why we hear workmen speak of letting down things gently. For, if a box of 100 lb. weight was placed easily down on a floor, no injury would accrue; but if dropped at a height of an inch and a quarter, the momentum would make it fall with a weight of 200 lb.; and if at five inches, with a force of 400 lb.

A bird draws its head back, and strikes its prey with force, to destroy life.

A swan, with the momentum it can give its beak, will knock over a boy of fifteen or sixteen years of age.

A horse in kicking draws its leg up, and from the space it has to pass through adds to the velocity, and causes the frightful injury it can inflict.

The velocity gained by going down a steep incline will cause a body to rise up an opposite acclivity. There has been frequently exhibited a tramway placed around a large circle, and persons seating themselves in a little carriage, by descending a steep incline there has been sufficient momentum gained to carry them safely around the inside of the circle and up an opposite incline, where they were stopped.

A monkey drops a cocoa-nut from a height, that its shell may be broken. Some birds drop shell-fish on rocks, that they may feast on the food inside.

The *direction* of the force gives the direction of the moving body. Point a gun perpendicularly, horizontally, or obliquely, such would be the movement of the bullet, did not the resistance of the atmosphere and the gravity of the earth change the direction, and bring it to rest.

The accumulation of force by space is shewn by boxers always keeping their arms far back, that they may give a powerful blow when striking at arm's length.

Anchor-smiths, in wielding a blow, swing the hammer round, that it may have accelerated power in forming the ponderous instrument that has to grapple with tides and storms.

In pile-driving, a weight is pulled up to a great height and let fall, to force the beam into the bed of the river.

The distance a bullet may be sent depends much on the length of the barrel, by which force may be accumulated from the space. Thus, the deer-hunters and pigeon-shooters in America use enormously long-barrelled rifles.

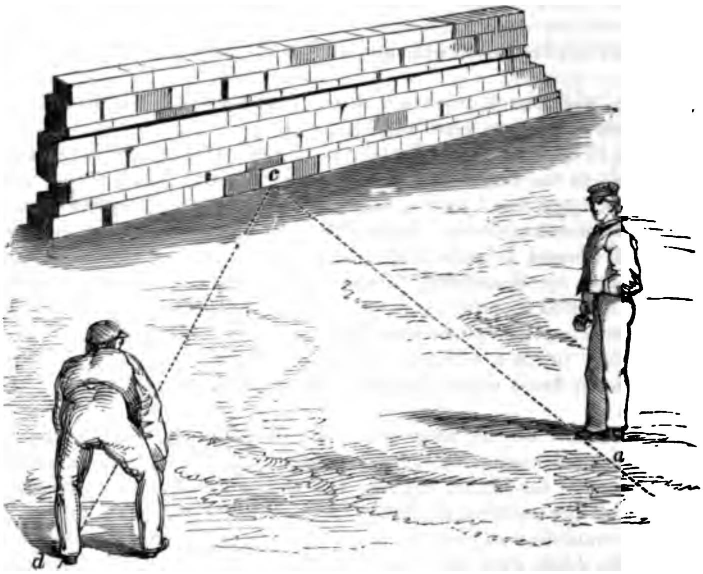
REFLEXION OF MOTION.

A ball or a marble driven in a perpendicular line against a wall, the re-action of the wall will cause it to rebound in the same line as it proceeded towards the wall.

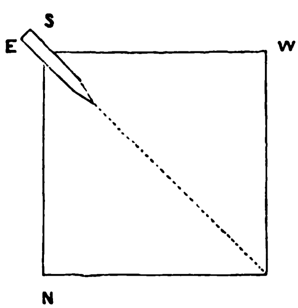
If a ball be bowled obliquely, on hitting a point it will rebound in a similarly oblique line, in an opposite direction.

The ball thus thrown by the boy at *a* hits the wall at *c*, and then progresses towards the boy at *d*, forming as equal an angle on one side as on the other, which may be known by drawing a straight line from the point of the wall where the ball hit. The angle formed by the line indicating the direction of the ball and by the perpendicular dotted line from the

point of contact is called the *angle of incidence;* and the *angle of reflexion* is the angle contained between the same perpendicular dotted line and the line drawn representing the path of the ball after it has rebounded from the wall. It is a general law, that these two angles are equal to each other, and this is the case in light as well as in other things.



DIAGONAL OF A SQUARE.



When one force acts upon a body, it moves in the direction of that force; but when two forces act at the same time, as it cannot move two ways at once, it takes a middle course, and this path is called the *resultant* or *equivalent;* that is, it is the result of a *composition of forces.*

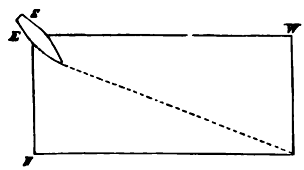
If a vessel has a strong east wind that would blow it to the west, with a current from the south which would carry it to the north, and these two forces, the wind and current, act equally, the vessel neither goes to the north nor the west, but takes a middle course between them, which is called the diagonal; and in this case the diagonal will be that of a square.

PARALLELOGRAM OF FORCES.

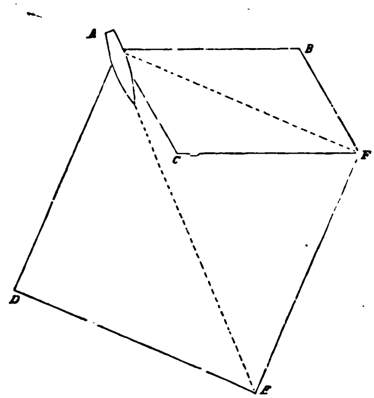
A parallelogram is a plane figure whose opposite sides are parallel and equal to one another.

When the current and the wind are not equal, then the motion is different, according to their degrees of strength.

Here the current is not so powerful as the wind, and the vessel is impelled so much further in the direction of the wind than in the direction of the current.



Scientific men call these forces *components;* that is, the two go to make one, and this one is the *resultant;* they can calculate them to a nicety; and, as of all laws of nature, make them a mathematical certainty. Suppose the force of the wind would take the vessel eight miles an hour, and the current six miles an hour, they square these powers; that is, say, 8 times 8 are 64, and 6 times 6 are 36; then they add the numbers together—64 and 36 are equal to 100, and the square root of 100 is 10, so that the vessel has gone by the two forces 10 miles in the hour, which is more than it would have done by either of the forces separately, for with one it would only have gone six miles and with the other only eight miles. This rule is true only when the two forces are at right angles to one another.



When two forces are almost in opposite directions, which may be illustrated by opening a pair of compasses almost straight, then the resultant line is very small, which proves that two such forces destroy each other.

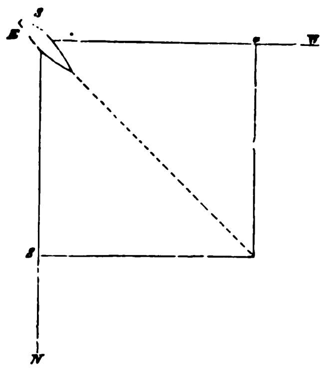
Finding a force which is equal to two or more forces is called a *composition of forces.*

Should three forces in different directions act on a body, then the resultant line can be found thus :—

Here are three forces, *a b, a c,* and *a d;* the resultant of *a b, a c* is first found in the manner before stated, which will be the dotted line *a f;* then the forces *a d* and *a f* will give the line *a e,* which is the resultant of the three forces.

RESOLUTION OF FORCES.

When one force acting upon a body produces a certain effect, and it is desired to know what two or more forces are equal to that one force in producing the same effect, or what one force is equal to the effect of two or more forces acting in given directions, this is called a *resolution of forces.*



Thus, if a vessel be sailing south-east, the resultant line of the force of the wind is known; but if we desire to find how much south wind and how much east wind effects this resultant line, a line is drawn in these directions from the position of the vessel in the diagram adjoining; and from the end of the resultant line, cutting through the south and east lines, the length then to *s* is so much south, which is the difference of latitude; and the length to *e* is so much east, which is the difference of longitude; and thus the situation of the ship is determined.

ACCELERATION OF MOTION.

The universal principle by which bodies are held together and drawn into company has been noticed as attraction. This pressing downwards towards the centre of the earth was explained as gravity.

If a boy throw a cricket-ball up in the air ten feet high, and catch it in his hands, he does not feel any particular action on his hands; but if he cast it upwards twenty feet, he receives a good smart blow on its return; and if thirty feet high, he has to ease the blow of the ball by giving way to it, or otherwise his hands might be hurt.

A ball dropped from the hand at the height of the head is easily caught by the time it reaches the breast; but the lower it gets the more difficult it is to catch.

This arises from falling bodies every moment they are descending collecting more velocity and momentum.

If a person be on the top of a mountain—say Arthur's Seat, Edinburgh—and he moves a large stone over its side, it goes the first few feet hesitatingly, as if with reluctance; but gradually, as it proceeds, its motion is increased to great rapidity, until it has rolled beyond the foot of the mountain, along the plains below.

In the coal-districts, where there are slight inclines for the wagons, they have to be put in motion with a lever, and can, when first on the incline, be easily stopped; but when they have proceeded a little way the motion increases, until a velocity is attained which no man could suddenly stop.

If treacle be poured from a vessel, it appears over the cup in a large thick mass; but when held high up, the stream dwindles into a thin thread. Still a vessel will be as quickly filled by the thread as by the thick mass, for the bulk is made up by the velocity of the thin stream. So rapidly does it fall that time is required before it incorporates with the mass, lying at first in threads on the surface.

A person may spring from a chair and feel no harm; in leaping from a high window he may receive a sprain or a broken bone; but in jumping from a house-top he would probably be killed. This arises from the increased speed of his fall from the space passed through and momentum.

When a body is let fall from a height, as the attraction of gravitation

is continually acting, so the velocity increases every instant. By accurate calculations, it is found that the increase is exactly as the odd numbers 1, 3, 5, 7, 9, &c.; that is, in one second of time a body falls through 16 feet of space; in the next second, it passes through three times 16 feet, that is, 48 feet; in the third second, its progress is five times 16 feet, or 80 feet; in the fourth second, seven times 16 feet, or 112 feet: thus, the whole of the space passed through, in four seconds will be 16, 48, 80, and 112 feet, which added together is 256 feet. The rule applied to this is, "the spaces described by a body falling freely from a state of rest increase as the *squares* of the times increase." Thus, then, the seconds, that is, "the times," multiplied by themselves, "the squares," and this result multiplied by sixteen, that is, the space described by the first second, the answer will be the number of feet through which the body has fallen. By adding the increase of velocity together, and taking the square root of the result, "the time" employed is represented. Thus, add together the first second one and the next second three, which is equal to four, then the square root of four is two, which is the time; in the third second there are one, three, and five to add together, which is nine; now the square of nine is three, which is the time employed.

Were a weight dropped from a pillar, and the time of its falling to be three seconds, then multiply three by three, which is nine, and sixteen multiplied by nine, the result will be 144 feet—the height of the pillar.

A stone dropped down a well or mine, and the time of its falling being found by a watch to be four seconds, four times four is equal to sixteen, which, multiplied by sixteen, the depth of the well or mine will be 256 feet.

The real distance a body falls in a second is 16 feet 1 inch; but the use of a whole number is less confusing to the comprehension than when fractional parts are introduced.

Every thing falls with the same velocity, but the resistance of the atmosphere acts more on one body than upon another. If this were not the case, a feather would fall as rapidly as a bullet.

Before leaving this part of our subject, it may be as well to remark, that, although the *spaces* described by falling bodies are as the squares of their *times*, yet the *velocities* do not increase in the same proportion. The *velocities* are *as the times*; thus, at the end of the second second, the velocity is 64 feet; at the end of the third second, the velocity is three times 32 feet, that is, 96 feet, while the space described is 144 feet; in the fourth second, it will be four times 32 feet, or 128 feet velocity, and the space described 256 feet.

A circular saw moves with such velocity that a piece of hard wood is cut more easily than a cheese with a knife.

Metal and iron are also cut through with facility.

Soldiers have recently exhibited feats, exemplified by cutting through small blocks of lead with one blow of a sword. In doing this they bring the sword, hand, and arm far back, then swiftly swing it forward.

RETARDED MOTION.

If a bullet be shot perpendicularly upwards from a gun, its motion gradually decreases in its flight until it comes into a state of momentary rest, before it returns in its downward flight, its velocity increasing as it

approaches the earth. Gravity keeps pulling at it as it ascends, and thus decreases or retards its motion; and the resistance of the atmosphere aids, the latter also preventing it coming to the earth with the same velocity as it left it. Its motion upwards depends on the velocity with which it was dispatched, and is calculated in the same manner as downward motion.

If the fountains at Trafalgar-square be noticed, it will be seen on the water issuing from the pipe, the velocity causes it to be a thin stream, which gradually widens until spreading like a tree, from loss of velocity, it descends. A ball might be placed upon the top, which the velocity would support, as in the little fountains in the shops of filter-venders.

A boy, on the same principle, blows through a tobacco-pipe, and causes a pea with a pin through it to dance in the air.

MOTION IN ELASTIC BODIES.

An elastic body yields to pressure, but strives to resume its former shape. Thus, a piece of cane when bent endeavours to gain its former straightness.

If a row of billiard-balls be placed in contact, and another ball be driven against the first one, the driven ball stops, but it communicates its motion to the next, which again transfers it to its neighbour, and so on, until the last ball having no other to communicate it to, flies off with the motion of the ball that took up its place before the first one.

Should four balls be hung up with their sides touching, and the outward one, keeping the string tight, be raised up and let fall, this one will become stationary, and the outer one on the opposite side fly off with the motion of the one that fell down.

A boy accustomed to play at marbles knows when he hits another a fair dead shot; the one he hits with stops, and the other flies away with the speed of the one he shot at it with.

Soft substances, such as clay or putty, being non-elastic, when they meet with equal velocity, stop and stick together, as their actions destroy each other.

ACTION AND REACTION.

This is self-evident, as explained in law 3; but the following examples will assist in elucidating the subject:—

On board our men-of-war vessels, there are contrivances for the recoil of the cannon that are fired, for the cannon receives as much momentum as the ball; but the momentum being distributed through the large mass of the cannon, it is more easily arrested than the smaller mass of the cannon-ball.

Most persons have felt the blow of a gun on firing it, when not placed tightly against the shoulder. By having it placed to the shoulder, there is the greater mass to receive the momentum.

A vessel chasing a smuggler retards her motions in firing her bow guns, while the smuggler quickens hers by firing her stern cannon.

It has been proposed to fit up steamers, to be propelled by squirting water from the stern.

A man being weighed in a scale, and pressing his weight on a stick

placed on the ground, will send the scale with the weights down, while he will rise.

A man trying to get a boat out of shallow water, pushes the end of the boat-hook against the ground, and thus eases the boat of his weight: were the ground soft, this would not take place; but when hard, as it resists equal to his pressure, a weight is taken off the boat, and it can then be floated into deeper water.

The paddle of a steam-boat drives the water to the stern, and the boat advances equally. A vessel full of water hanging up, and having a hole made in it, will recede to the side opposite the hole. If the hole be oblique, it will turn round.

A ball thrown against a pane of glass is resisted according to the strength of the glass; and, in passing through, loses as much of the momentum it possessed as is equal to the resistance of the glass. If the velocity of the ball be great, the glass will not be fractured, but a small clean hole made; this is from the very short space of time allowed for resistance. It is a common saying, in this latter case, that the pieces carried away have not time to warn and frighten their neighbours.

A sailor will say the *wind* of the ball hurt his body and threw him down, when actually the ball has grazed him.

The Marquis of Anglesey did not know that he had been shot in the leg until some one informed him of his misfortune. A rapid ball only injures the part struck—a slower one bruises and injures all around where it hits.

The slightly propping a door and firing at it with a cannon-ball without disturbing its position, and firing with a pistol-bullet through a sheet of paper without knocking it over, are common experiments to illustrate that forces must be also measured by space and time.

That momentum distributes itself through the entire mass of a substance, was illustrated by a knowing fellow who exhibited himself in public places; his great feat was lying down on his back and having a large piece of freestone lifted upon his breast, then a number of powerful quarrymen to split the block by blow after blow given to a wedge that had been previously inserted. The weight of the stone he bore on his breast and arms, bent upwards, while a many-folded blanket was laid over his body. Now, though double the momentum of the hammers was given to the stone, yet from its size, the stone was scarcely moved by the momentum of the hammers, and the shock only very slightly felt by the "wonderful herculean man!"

CENTRE OF GRAVITY.

Every connected mass of atoms of matter has a certain point about which all the other parts balance or have equilibrium, which point is called the centre of gravity. Every one of these atoms is subject to the force of gravity, or weight, all of which forces are parallel to each other, equal, and act in the same direction, their effect being the same as if it were a single force applied to a single point; this point is the centre of gravity. By this point the mass may be lifted; or if supported on it, that is, the weight counteracted, then the mass or body is at rest. This point has always a certain position in any given body, and therefore the part may be known about which, in every position, the mass will have equilibrium. Now, though we may say the centre of gravity will be exactly in the centre of

an exactly square piece of wood, this may, on being tested, prove not to be the case; for part of this wood may, when growing, have faced the sun, and another part not have done so; hence the former part will be more dense than the latter, and the centre of gravity therefore not be where theory would point out as its position. If we place a stick across a finger, the part where it balances on the finger will be the centre of gravity. In a ring, the centre of gravity does not exist in the ring itself, but in the centre part where the particles of which it is constituted would balance.

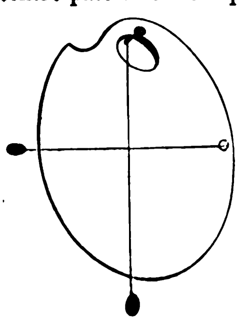


fig 21.

If we take a painter's palette and let it hang freely by the edge in its longest direction, and then drop a plummet with a line, the centre of gravity will be in the line that touches the surface of the palette, and on this line it will balance. Turn it sideways, let it hang freely, and again drop the plummet and line, which will bisect the other line, and on this line the centre of gravity will be found to exist, as the palette will balance. Hence, then, as it is found to be in both these lines, the centre of gravity desired to be known is at the point where they cross each other.

Geometrically to find the centre of gravity of a triangle $a\,c\,e$, draw a line from a to b, and from c to d, bisecting the opposite sides; and as it will balance on either of the two lines, the centre of gravity is in both the lines at the point f, where they intersect. Thus $a\,f = \frac{2}{3}\,a\,b$, therefore a line from one angle bisecting the opposite side, having measured off from the angular point a distance of two-thirds of its length, gives the centre of gravity of a triangle. Having given this mode of finding the centre of gravity of a triangle, a pyramid constructed in the form of so many triangles may have its centre of gravity easily proven. From our knowledge of the pyramidical form, we perceive that the centre of gravity lies low, and the broader the basis, the more firmly will a body stand. If we attempt to overturn any substance in the form of a pyramid, we find that its centre of gravity has to be lifted considerably, and also the whole mass of which it is comprised. In fact, according to the breadth of the base of the body, compared with the height of the centre of gravity above it, will be the rise of the centre of gravity, which will be more easily comprehended by the following diagrams.

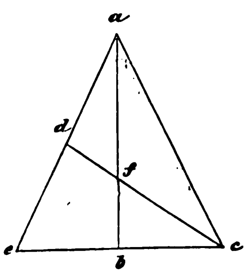


fig. 22.

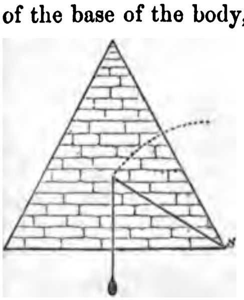


fig. 23.

Fig. 23 represents a pyramid in which, from the breadth of the base, the centre of gravity is low, which may be considered as supported on the plummet-line; now if this had to be turned over so as to be supported on the part s, the centre of gravity would describe the part of the circle shewn by the dotted line drawn from s, as that is the part on which it would rest on turning, called

the centre of motion. The greater the distance that the centre of gravity, as shewn by the plumb-line, is from *s*, the further will the centre of gravity be from the top of the circle it moves in in turning over, and the greater will be the rise, and the resistance nearly equal to the whole weight. The line marked by the plummet is called the line of direction of the centre.

In fig. 24 the base is also broad, and therefore firm, from the centre of gravity having to be considerably raised before the body can be overturned.

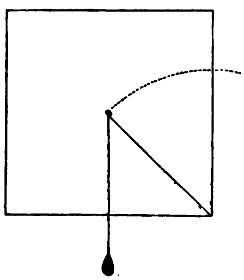


fig. 24.

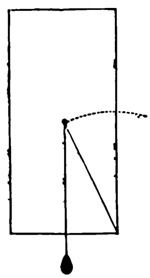


fig. 25.

fig. 26.

In figs. 25, 26 the commencing path of the circle described by the centre of gravity is not so perpendicular as in the former figures, and therefore they are less steady on their bases.

In fig. 27 from the narrow base, and the high position of the centre of gravity, the slightest movement would make it fall, as the motion described by the dotted line must be descending.

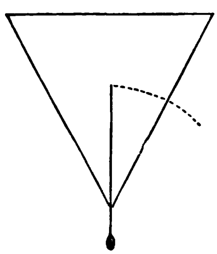


fig. 27.

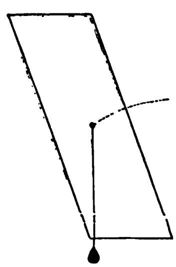


fig. 28.

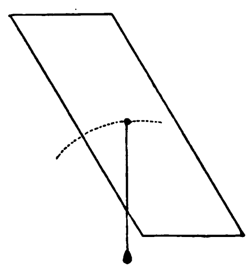


fig. 29.

Fig. 28 shews an unstable position on one side, and a more stable one on the other, for the sustaining base is actually narrowed; the line of direction falling within the angle from the centre of gravity to the corner of the base, the body is still supported, but if moved over at the right side the centre of gravity would be lowered, and the body soon fall.

In fig. 29 the line of direction falls beyond the base, and therefore the object must fall.

Fig. 30 is an oval body which, when on a level plane and moved, the centre of gravity will describe a curve like that of a pendulum, returning to its former position, but not turning over.

Fig. 31 is an oval on one end, and if moved either on one side or another, as the motion of the centre of gravity is downwards, it will fall.

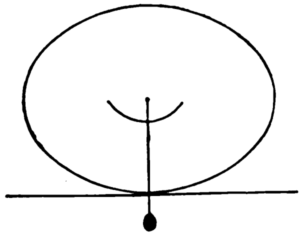


fig. 30.

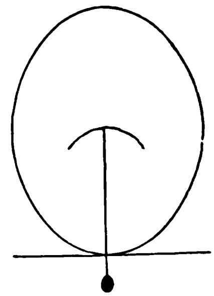


fig. 31.

A globe or ball, fig. 32, when on a level plane, is supported on a single point; but as in every position the centre of gravity would be the same distance from the sustaining point, it has no tendency to move. When it is moved, the centre describes the straight line *a b*. The equilibrium in this case receives the term indifferent, as it makes no attempt, on being moved, to return to its former position, or move from that in which we place it.

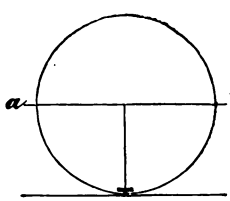


fig. 32.

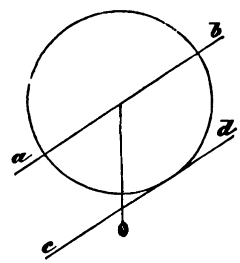


fig. 33.

If the ball or globe be placed on an inclined plane, fig. 33, and rolls down, then the centre of gravity will have an oblique motion, as in the line *c d*.

Place a walking-stick, fig. 34, on the edge of a table *a b* so that it would fall if left to itself, attach to it a weight *e* by a cord *d*, place a rod *c* against one end of the stick and the top of the weight, which rod must be of such a length as to shove the weight a little underneath the edge of the table, and the whole will rest steadily in their positions, because the cord being out of the vertical, no lateral motion can be given to the weight without raising the centre of gravity of the system; the stick in falling must turn round the edge of the table; in so doing it will describe the dotted part of the

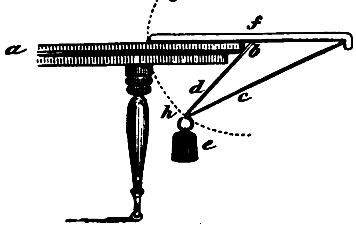
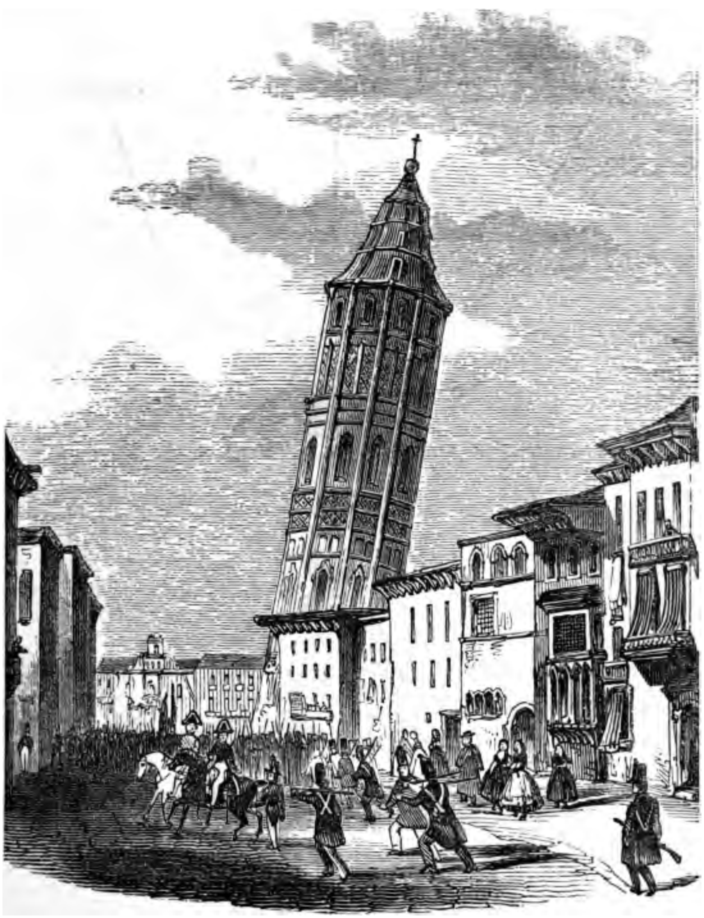


fig. 34.

circle g, lifting the centre of gravity in the arc h; and as the weight is heavier than the stick, this is against the laws of gravity, hence an equilibrium is preserved.

If a cart or coach be loaded so high that its centre of gravity is at a considerable height from the base, then a slight inclination on either side, throwing the line of direction outside the wheels, will cause the vehicle to be overturned.

In the human body the centre of gravity must be directly above the points of support, which are the feet. If, therefore, we take a load on our backs, we bend forwards, so that the centre of gravity may be above the point of support; or in taking a weight in the arms we lean backwards. If we wish to stand very firmly, we widen the base by placing the legs at a greater distance and turning out the toes. The walking on wooden legs or stilts requires practice, so as to preserve an equilibrium in an unstable position.



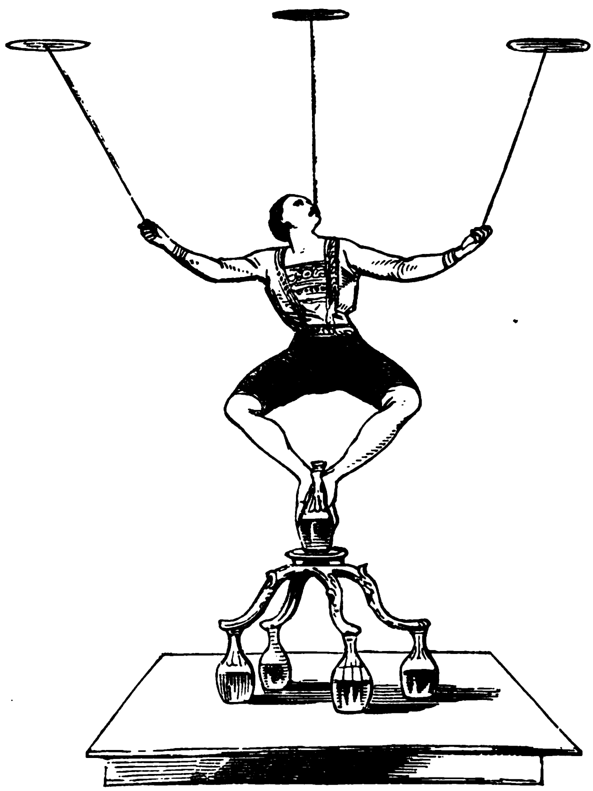
Leaning Tower at Pisa.

On looking at the ancient statue of Hercules, the feet are seen turned out, giving an appearance of strength and firmness. In that of Mercury, where swiftness is the object to be personified, the feet are nearly straight, and the toes only touch the ground.

When we walk up a hill we lean forward, and in descending lean backward, from the necessity of preserving the centre of gravity in its right position; stout persons also lean backward, as if proud of the incumbrance on their bones.

The tower at Pisa overhangs its base several feet, but the tenacity of its materials holds it together, and its centre of gravity is preserved.

The London Monument inclines much, as do several tall church-spires. But of all enduring monuments are the broad-based Pyramids of Egypt, which stand as it were milestones to measure, from the darkness of the almost lost ages, the progress of the age of utility in the present; at the same time, to shew us that as gigantic ideas and powers of execution then existed as any at the present day.



The juggler preserving his centre of gravity

MOTION OF SOLIDS, CALLED VIBRATION.

If we take hold of one end of a rope which has the other end fastened, say to a hook in a wall, and give it a quick shake, a kind of wave proceeds along the rope until it arrives at the other end, when it commences its journey back, and returns to the hand. Its form on proceeding from the hand resembles the letter ɷ turned sideways; the lower part is termed the depth of the wave, the higher, the height, and from one extremity to the other, the length. The half-circle by which we state the height is termed "the phase of elevation;" and the lower half-circle by which we state the depth is termed "the phase of depression." On the wave returning, the high part is opposite the lower, and the lower opposite the high part, thus:

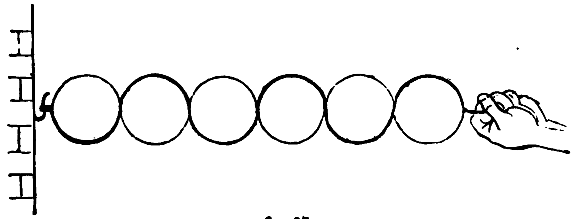


fig. 37.

If we place a long thin palette-knife with the handle stationary, then pull the blade to one side and let it free, it curves to the other side, and vibrates with decreasing force until it becomes stationary again. In these movements the atoms of which the blade is composed must have been alternately separating and going close together, until they resumed their original position; which is always the case when the force is not so great as to disperse them abroad, as they naturally seek a state of equilibrium.

Stationary vibrations are those that appear when we pull the middle of a tight string fastened at both ends, and then let it go; the vibrations are greatest in the middle, and gradually lessen towards the ends, every atom being engaged in the action until it once more settles into a rectilinear position.

The law of these movements is the same as those of the pendulum; that is, the movement on each side of the position they were in when at rest is performed in equal times, but the motive power is elasticity, not gravity.

If a palette-knife or piece of steel be twelve inches long, and makes three vibrations in a second of time; and if it be shortened to six inches, it will make twelve vibrations in the same time; and if made three inches long, its vibrations will be thirty-two in a second. Thus when two pieces of steel are equal in form and material, the vibrations will be equal; while the rapidity of the movements increase with the diminution of their length.

A ball fixed to the lower end of a helix of wire, a "baby jumper," or a glass "Jacob's ladder," when given a little motion, advances and recedes with pleasing easy longitudinal vibrations.

MECHANISM OF THE HUMAN FRAME.*

By examining minutely the structure of many insects, we discover they are provided with formations for the purpose of fulfilling the destiny of their peculiar conditions; that their saws, rasps, gimlets, needles, lancets, spades, hooks, hinges, awls, tweezers, pincers, and other tools, afford lessons in which man may profitably learn the best construction of such implements.

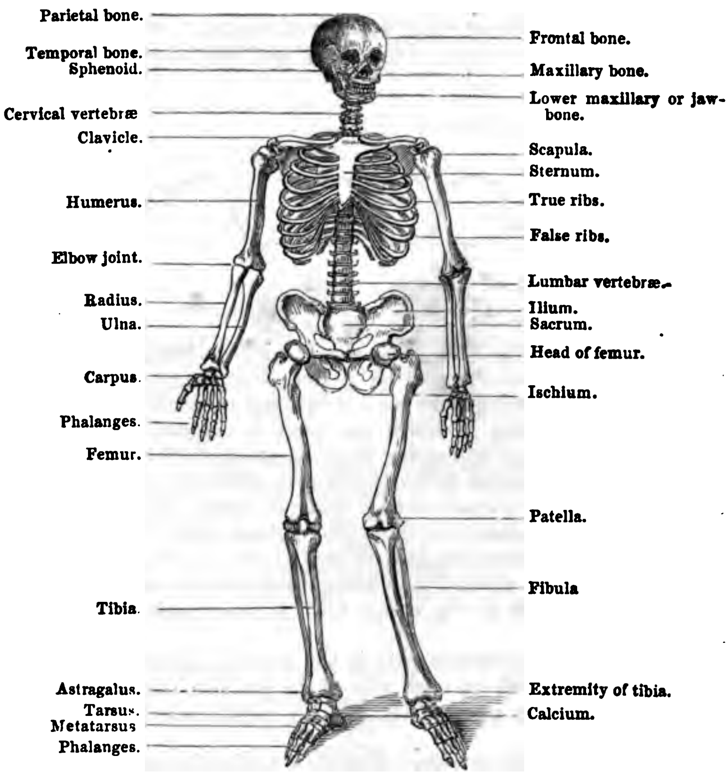


fig. 38.

In that most admirable of mechanisms, the human frame, we have surprising examples of economy of material, combining lightness, force, firmness, elasticity, leverage, hinges, joints, sockets, motion, resistance, security, and grace, so that its description becomes an appropriate section

* Following the usual plan of treatises on Natural Philosophy, we ought here to introduce our explanations of the principles of *Mechanics;* but we found the interesting and important subject so increase in bulk, as to defeat the purport of this series of instruction-books; so that we resolved to issue it as a separate treatise, having added to it details of machinery, that the work might be complete, either for those seeking general useful knowledge, or intending to pursue the science as a profession.

in illustrating the principles of Natural Philosophy. In comparing the ingenious contrivances of talented engineers with the perfection of the framework of organised beings, we cannot but mark with reverential awe the vast distinction between the works of man and the works of God.

The loftiest portion of the solid human frame is technically called the *cranium*, a word derived from the Greek, signifying a *helmet;* but it is better known as the *skull*. The form of this part is that of an arch, the best to give strength, whilst the tenacity of its material is so great as to resist shocks in all directions.

When the living principle early acts in the germ of the future human form, the covering of the brain is but a flexible tenacious substance, which progressively shoots out bone, like delicate icy crystallisation on water, until the whole becomes as so many scales bound together by a membrane. The edges overlie each other, and the whole is soft and elastic in early infancy; gradually, as years approach to teens, the bone hardens, and processes form for dovetailing it neatly and compactly together, which seams or joinings are called sutures. During the thoughtlessness and mishaps of youth, these joinings are not perfected; and thus when an unlucky blow is received from a fall or otherwise, its effects are dispersed at the edges of the sutures, and the vibrations being checked, the injury is comparatively harmless. As maturity creeps on, and consequently caution and power, these minute but strong dovetailings become thoroughly and firmly knit, and the whole a hard case of bone.

On looking at the mature skull, it presents to our view, first, the *frontal* or bones of the forehead, that continue backward to the sutures, which may be felt on the crown and sides of the rounding of the head. From this, and comprising the principal part of the sides, top, and back of the head, are the *parietal* or wall-bones. Below the last-named is the *occipital* or back of the head-bone; in it is the hole through which passes the continuation of the brain into the spinal bone. The *sphenoid* or wedge-bones lie behind the orbits of the eyes, and touch the frontal and *temporal* or temple-bones; the latter contain and protect the organs of hearing, and overlie the parietal bone, being joined to it by what is termed a squamous or scaly suture.

The bone of the skull consists of two tables or layers, the one external, the other internal, separated by a spongy substance, resembling in form the cells of a marrow-bone, unequally spread, and called the *diploe:* this and the outer covering, the scalp and the hair, by their elasticity, aid in deadening the effects of a blow.

The outer dovetailed table is fibrous and tough, thus admirably suited to resist the blows to which its position exposes it; while the inner table, called *tabula vitrea*, or the glassy table, against which the delicate brain is in contact, is smooth, dense, and brittle: this latter quality would render the little projections in dovetailing easy to be snapt; therefore, with that wondrous adaptation to every circumstance, the edges of the joinings are laid in contact. In the operations of man, tough wood is dovetailed, but the edges of china or glass that have to be in contact are merely laid close together.

When a man receives a severe blow on the head, it may cause such a vibration throughout the brain as to deprive him of sense or motion;

and a severe partial blow usually fractures and indents the part struck. A blow with a sharp instrument may cut into the brain itself, and not render the person insensible; while a blow with less force, but received from a broader surface, being resisted by the arched form of the head, usually cracks the bone at an opposite part to that struck. This bears a similitude to the piers of a bridge being cracked and thrust out when not strong enough to resist the weight upon the crown of the arch. The utility and power of the arch in the erections of dwellings for societies of the human family seems to have been known in the early history of the world, as it has been discovered in the buildings of the buried city of Nineveh.

In the eggs of birds, and various seeds of vegetation, nature protects the nucleus of future life with a limy or flinty arched encasement. The brain of man, the seat of glorious mind, that has to direct us in our duties as to the present and future life, is carefully protected throughout existence in the hard, bony, arched case we have just described.

Let us for a moment glance but at one case, to see the necessity for such a beautiful strong covering as is provided by ever-watchful Providence. A youth received a blow on his head, given by his tutor with a ruler; this caused a slight depression of the skull, which pressing on the brain, the promising youth fell into deplorable idiotcy. A few miserable years thus passed away, when a skilful medical man, undertaking the case, by an operation removed the pressure, and at once restored the patient.

The *lower jaw* has a hinge-joint that permits of two motions, the greatest being in a perpendicular direction, for the purpose of allowing the mouth to open and shut, and the other in a less degree to move from side to side. Thus it has a combination of the action of the jaws of a tiger, which is a simple hinge-joint, similar to that of a pair of pincers, and a lessened lateral motion as that of sheep; one action being for the purpose of cutting, the other for grinding. The voluntary muscles of the human body are composed of a number of nearly parallel fleshy bundles, enclosed in a fine covering; these bundles consist of round hollow fibres, the diameter of each fibre being about the 400th part of an inch, containing a glutinous fluid, and threads about the 15,000th of an inch in diameter. A muscle when contracted is not less in size, but broader than when extended; the action of contraction in some is effected by fluid being forced into the tubes, which swells out the sides and shortens the length; but in the voluntary muscles, the elasticity they possess is what renders them of such value in the functions of the human body. The temporal and masseter muscles, that move the lower jaw, are short and strong; and as they act at right angles to the line of the jaw, their mechanical advantage, or lever power, is greater than those in many other parts of the body. This is what gives the great strength in biting hard substances, and power to crack the obstinate shells of nuts with the back teeth, like in the hinge part of a door.

The first *teeth* are small, to adapt them to the size of the mouth; these fall out, and are replaced by others, suitable to the enlargement of the frame; and finally, in maturity, the teeth of "wisdom" complete the set. Some are formed like wedges and chisels, to cut and divide substances,

others are for tearing and grinding. Thus we have an approximation to the pointed, jagged, and sharp teeth of the tiger, and the cutting and broad, rough teeth of the sheep. The beautiful hard enamel by which the teeth of animals are covered, causes uncivilised nations to use them in various purposes of rude manufacture, while in our own country the tooth of a dog was used as a polishing tool by bookbinders.

Next to the head in importance to the functions of sensation, and as important as the brain itself to the continuation of life, is the spinal marrow. Some physiologists call it a prolongation of the brain, while others think the brain a continuation of the spinal cord, rearing up and spreading out like the branches of a tree.

In the grand design of the framework of the human body, not only is there a powerful protection afforded by the formation of the spinal bony column for the nervous matter which fills its cavity, but while it sustains the head, and bends to the motions of the body, it also is the connection of the higher and lower parts of the skeleton.

Behind the bones that keep the body erect a spinal process projects, from which the common name given to the column of *spine* is derived; the separate bones of which it consists are called vertebræ. In form the spine resembles an italic *ſ*; the lower end tapering off; joining this root part it curves inwards and the bones of the vertebræ here are the largest, and somewhat like the stem of a tree decrease upwards. Twenty-four distinct bones constitute the true or movable vertebræ. The part we designated the root is composed of a triangular-shaped bone called os sacrum, and another os coccygis, which being in four pieces, and from resemblance, are frequently termed the false vertebræ.

The bones are nearly cylindrical, with a perforation behind for the spinal marrow, and have the projecting spinal process we referred to, as well as two at the top and two at the bottom of each vertebra. The first five large vertebræ are called lumbar, that is, pertaining to the loins, above which are twelve called the dorsal or back vertebræ, to which are fastened the ribs, forming with the breast-bone the part called the thorax; the seven piled on the last-named are called cervical, or belonging to the neck,—these curve first in a forward direction and then recede in the upper back part of the head, giving that graceful form so admirable in the neck; the highest but one of these, from a remarkable bony process it possesses, is named the vertebra dentata; and the topmost one, that immediately supports the head, the atlas; and justly so, as it bears upon it the individual world the mind creates: from the ideas that form the links of the mental chain organised beings recognise themselves from each other; when it is broken, the living mass of matter is in that pitiable state called insanity; and when annihilated, by the flight of the imperishable soul, there is the darkness and vacuity of death.

Having piled up this wonderful column from the foundation, let us now see how inimitably it is adapted to the purpose of its design. Beyond that of protection to the life-constituting cord of matter, it has to possess elasticity, to prevent any jar upon the brain, and therefore to let the head be borne with the ease of a carriage upon springs; it has to be flexible, that the body may move in all directions; firm, to support the upright position of the body, a fulcrum to the muscles, a prop to the ribs; and it has to possess strength, that weights may be borne on the shoulders and back,

It is related of Topham that he lifted by his shoulders three hogsheads of water, weighing 1836 lbs. ;—wonderful, then, is the mechanism of this column!

First, we may note the manner of the head being placed on the spine. There are two prominences at that part of the skull called the occiput, that are received into two corresponding cavities of the atlas; by this the head can move forward in the manner we do when we nod, but the atlas-bone turns horizontally round the tooth-like process of the next bone, the vertebra dentata, and thus the head moves from side to side; therefore there is the up-and-down and rotatory motion effected by these two bones. But as these motions are limited, and man requires more, the flexibility of the spine comes to our assistance, and thus we can freely move the head in any direction. Now, as the joint of the head and the spine is not quite in the centre of the bottom of the skull, the head, unsupported, would drop forward; to prevent which in the living subject there is a strong ligament which comes from the cervical vertebræ, and is fastened to the bottom part of the skull. When in a sitting position, and sleep overcomes us, the muscles relax, and the head drops forward.

The contrivance to give elasticity to the spine consists of a soft, firm, elastic substance, about half as bulky as the vertebra itself, that is inserted between each vertebra; this in some parts is thicker before than behind, so that when we stoop forward, it is compressed, and the surfaces of the bones of the vertebra become more parallel to each other than before, and no opening between takes place; then, when the pressure is relieved, the elasticity, like a spring, sends the body again into an erect position; while any danger that might arise from a shock at the lower part is removed by this body of elastic substance, which prevents the hard and unyielding bone, which resembles a strong irregular ring, or double rings, or double arches, from being in contact.

The column is accurately described as a chain, from its firmness and flexibility. The number of the joints gives the pliancy it possesses, which is greater in the loins, being more required in that part than in the back where firmness is necessary, and greatest of all in the neck, on which has to move that part containing the organs of sight. Then to preserve uninjured the spinal marrow, and yet to allow of free movement of the parts containing it, the processes and projections of the vertebræ so lock in with and overlap each other, as securely to prevent the slightest derangement of the bones, and the free unharmed continuation of the delicate cord. Though we may bend the back to a great extent either backward or forward, yet its many links prevent any part from being overstrained. We know that if we give considerable inclination to a cane, that although, on the whole, there is a great bend, yet each individual part is only bent to a small extent. To add still further to the compactness of the elasticity, a ligamentous substance joins the roots of the spinous processes to each other. In fact, the whole is really stronger than if a solid column of bone had been inserted, so perfect and far-seeing is the design of the great Architect of the human race.

The contortionists who exhibit their feats in the streets and public places of amusement, rarely injure their spines; and diseases of that part are rare, excepting those brought on by a false and pernicious system of education. Keeping the body too long in an upright position, and not

allowing free scope to the excess of animal spirits in the young, is an outrage on divine laws, frequently retaliated by a distortion of that graceful portion of the human body. The bandaging of the youthful frames of that perfection of the human form exhibited in the loveliness of the female, with bars or splints of steel and whalebone, to distort them from the comeliness and elegance of nature's outline, is distinctive of an obliquity of intellect and ignorance of beauty, that is abhorrent and highly culpable. Ridicule and pity the Chinese ladies, indeed! when pains are taken to pervert the beneficent laws ordained by an unerring Godhead, to render a creature divinely perfect a deformed object throughout life—to entail frightful diseases by inhuman fashions—to invite an early tomb for a loved and loving offspring, by the majority of highly civilised and proudly intellectual ladies of Britain, is beyond mere pity, as it springs from the tyranny of authority, and approaches the precincts of infidelity. Dr. Arnott, in his philanthropic career, having no doubt found these devotees to a pernicious fashion inaccessible to reason, at last tries the effect of placing the matter in a ridiculous point of view, and remarks—"It would be disgusting to see an attempt made to improve the strength and shape of a young racehorse and greyhound, by binding light splints or stays round its beautiful young body, and then tying it up in a stall; but this is the kind of absurdity and cruelty which has been so commonly practised in this country towards what may well be called the most faultless of created things."

Forming a powerful bony elastic exterior to a hollow interior is accomplished by the *ribs* attached to the spine. The ribs are long, curved, flattened narrow bones attached at the back to the spine, or that part called the dorsal vertebræ, and their transverse processes being joined in front by an elastic cartilage affixed to the sternum or breast-bone. They are twelve in number; the uppermost seven are called the true ribs, and the lowermost five, the cartilages of which do not reach the sternum, are named the false ribs. A great security to these bones arises from their not being straight, but hanging downwards like the lower part of the sunshade ladies affix to their bonnets; but there is another advantage: in the action of filling the lungs with air, the ribs rise up and enlarge the space for the reception of the breath, while the great elasticity of the cartilage aids this important action, and also gives way to any sudden blow. This could not be so well effected, if instead of the cartilage there had been a bony joint. In stooping forward or on either side, the elastic substance readily yields, and recovers itself by its spring. "The muscles," says Dr. Arnott, "which have their origin on the ribs, and their insertion into the bones of the arm, afford us an example of action and reaction, being equal and contrary. When the ribs are fixed, these muscles move the arm; and when the arm is fixed, by resting on a chair or other object, they move the ribs. This is seen in fits of asthma and dyspnœa" (difficulty or shortness of breathing). As age advances, the cartilage becomes bony, and hence less suitable for violent exertions of the respiratory organs; this should lead us to be tender of those who have reached "the evening of life;" and truly are men philanthropists, who would provide ease and comfort, after a certain age, for those who have, unprofitably to themselves, spent the energy of their prime of life in labour.

The *shoulder-joint*, by which we can exert great strength, and which has

such freedom of action, is formed by a round head of the shoulder-bone, called the humerus, which is placed in a shallow cup of the blade-bone or scapula, together forming a ball-and-socket joint; there are two strong bony projections above and behind that keep it in its place, and the ends of the bones are enclosed by a thick and strong membrane, so that dislocation is provided against. The two objects of strength and extent of motion are thus carefully secured; and to add to the latter, the shoulder-blade holding the round head of the arm-bone slides about itself upon the hollow of the chest, held, however, within bounds by a strong brace to the breast-bone.

The *clavicle* or collar-bone is of a slightly arched form, attached to the breast-bone and blade-bone in a very shallow cavity. It is of great strength, and from its situation liable to accidents. Resting on it, and the bed of muscles near, great burdens are borne in many industrial occupations of man.

At the upper and back part of the chest is the *blade-bone*, giving the mechanist an example of lightness combined with strength. When the wheelwright desires to give the best form to his work, he makes the felly, the spokes, and the nave strong, and bends the spokes inward, in a manner termed *dishing*; and thus is the blade-bone constructed, slightly arched, with its principal strength at the edges and spines, and other parts thin and light. This simple and incomparable mode of construction is found generally in animals possessed of bony frameworks.

Joined by a hinge-joint at the elbow is the *arm-bone*, or humerus to the ulna or *fore-arm bone and radius*; their motion here is only backward and forward, being restrained by strong ligaments from a lateral motion; thus it is a mere hinge, and can only be considered as a lever, as the muscles that move this part are long, very much slanted, and have to act near to the fulcrum or centre of motion. They have consequently to be very strong. In fact, it is calculated that the muscles of the shoulder-joint when lifting a man upon the hand, put forth a force of 2000lbs. As, however, there is ever wisdom and goodness in the works of Providence, what is lost in leverage power of the arm is gained in velocity; and thus by rapidity of action we make up for the sacrifice of power. How lost should we be, were the muscles different, formed for giving only immense strength, and accompanied with slowness of movement! We then could not speedily protect ourselves by raising the hand and arm, and from thousands of our present enjoyments we should be debarred.

The *wrist* and *hand* is divided by anatomists, first, into four bones that form the joint, with the arm-bone, called the radius: the first four bones are joined to other four, and these eight bones constitute the wrist; from this part proceed five bones, that may be felt at the back of the hand; joined to these are the three bones in succession of each finger, and the two forming the thumb. The turning round of the hand and wrist is effected by the radius-bone of the arm revolving round the ulna-bone, and of course the hand with it, without the wrist-joint moving. (It is obvious that this important bone derives its name from its power of motion in radii, or circles.) Not only is power of minute motion given by the number of small bones in the hand and wrist, but also the numerous shocks to which it is subject are deadened before reaching the higher parts of the arm. There is at the wrist-joint a strong band that passes around it, by which

the tendons that proceed from the arms for the movement of the fingers are bound together; were this not the case, we should have a hand about as shapeless as a hoof, and not much more useful; whereas we now not only have grace and beauty by this arrangement, but also strength with combined motion, and delicacy in partial motion, as of the fingers alone, instead of weakness. The mechanism of the hand is one worthy of careful study and deep reflection, being one of the principal sources of man's pre-eminence in creation, aided by reason, and displays in distinct characters the marvellousness of the works of the Divine mechanic.

In physical laws, the nearer a weight is to the fulcrum, the greater the amount that can be borne; as from experience we know we can sustain a weight on the arm near the joint, that we could not hold in the hand of the outstretched arm.

In the annexed diagram *a* is the fulcrum or point of resistance, *e* is the weight pressing downwards, and at *b* is the muscle that draws upward. Now if a two-pound weight be placed one inch from the fulcrum of the joint and then moved to the centre of the hand, and say the distance it is removed is fifteen inches, then to find the force with which the weight will press downwards, the distance must be multiplied by the weight. In this example, the foree that will press downwards will be equal to thirty pounds.

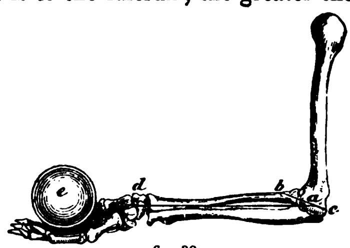


fig. 39.

To support the spinal column and affix the two columns of locomotion, the legs, there is a broad, light, hollowed bone called the *pelvis*. The two haunch or hip-bones are large, and where no strength could be obtained by its presence the bony substance is omitted. They present a broad surface, and are so placed as to form an inverted arch, that form conveying the greatest strength with economy of material. The hollow receives the lower part of the abdominal viscera. At the upper edge of the pelvis is firmly joined that part of the spinal column named the sacrum. Powerful muscles are attached to the bone, at the lower portion of which two large projections support the body when in a sitting position. The bones are connected by cartilaginous surfaces and large ligaments so strongly, that the whole must be destroyed before a part will yield.

The *hip-joint* is an admirable adaptation of the ball-and-socket joint: a large rounded head-part of the thigh-bone fits into a deep cup of the haunch, and is prevented from slipping out by thick and strong rising edges around the cavity. From the head of the ball, at the bottom of the cup and around the edges, are cartilages and ligaments that give security to the joint, and resist any force likely to displace the bone, while at the same time it allows a free motion to the foot, and ample range to the various actions of the leg.

In the *thigh-bone* the rounded head stands off from the shaft, but the projection is so placed that the strength and weight are thrown upon the shaft. The thigh-bone bends forward in an arched manner, and has knobs, to which are attached the powerful muscles of the leg; on the fore part of the bone the action of the muscles is great, and the curve of

the bone consequently gives a strength which it would not have had, the bone being straight.

The *knee-joint* is composed of three bones, curious in the arrangement, at the same time perfect for the purposes intended; the termination at this part of the thigh-bone appears of a rounded ball-form, resting on a shallow cup; it implies no strength, from the manner in which it is placed. To make up for this there are two strong lateral ligaments, and an immense ligamentous rope within the cavity of the joint. It is a singular property of the ligaments on the inside of the knees, that they become stronger the greater the strain upon them. The duties thrown upon the ligaments in this part cause the great elasticity of the limb so often called into use in violent quick exercise, and is another of those arrangements that are so inimitably suited to give advantage to man's position in the scale of organised beings.

The large muscles of the front of the thigh are affixed to the leg below the knee, and in their passage have to pass over the part where the joint of the knee exists. Before they arrive there they are contracted into a tendon, and become inserted into the bony structure in front of the joint, this part being called the patella or knee-pan, and is a valuable protection to the joint. By this arrangement a mechanical advantage is gained, from the centre of motion being increased in distance from the pulling power.

The bones of the *leg* much resemble those of the arm: the largest is called the tibia, leg, or pipe; and the smaller the fibula, or brace; they are angular, as a preservation against blows, and present a considerable surface for the attachments of the various muscles. A large flat portion of the tibia is covered only by skin, and is named the shin.

Between the two bones of the leg just named, which project at each side to form the *ankle*, is received the great articulating bone of the foot called the astragalus; when the foot is raised, this joint is fixed, and as the body comes down, the support is thus firm and steady to bear the superincumbent weight. The tendons are bound down by a ligament passing over them, as at the wrist; were it not the case, the foot would be more in the shape of an elephant's, and although the tendon would have greater power to draw up the toe on which it acts, yet its velocity of movement would be lost. One of the tendons passes along a groove under the bony projection of the inner ankle, exactly as we should place ropes over a pulley.

In the *foot* there are thirty-six bones; of these, seven comprise the tarsus, or part that reaches from the heel to the middle of the foot. By projecting backwards it forms a powerful lever, on which the muscles of the back of the leg, terminating in the Achilles tendon, act by lifting up the body and throwing its weight on the balls of the toes. Where the muscles of the calf are naturally small, as in the black race, the length of the lever of the heel is increased, and thus a provision to make up the other deficiency. It was by particularly noticing this fact of the graceful rising of the heel by the Achilles muscle, as if the foot were performing a circular motion, that made the ingenious American produce such a perfect and valuable substitute for a leg to those who had had the misfortune to lose that necessary member. It was shewn at the Great Exhibition, and

its all-sufficient qualities exemplified on the person of the inventor himself. On examining one of the artificial legs, it was found that the slightest inclination to raise the heel was followed by a perfect elevation, so as to allow the person to stand on tip-toe; and by bending the leg slantingly on to the toes, it went forward in a steady step, with a firm ankle, in a perfectly natural manner. It was thus, by an attention to the leverage and elasticity of the construction of the real leg and foot, that this clever apparatus for the unfortunate was so admirably contrived. Next to the tarsus are five bones laid parallel, called the metatarsus, from which proceed the three bones of each toe, except the great toe, which has only two. As the foot comes to the ground, the heel touches first, and then the balls of the toes, resting on a beautiful arch; the surfaces of each bone do not touch, as they have a layer of cartilage between each, and are lubricated with an oily fluid: and thus, in consequence of the number of joints and the nature of the surfaces, the whole is completely elastic and fitting for the various shocks in walking, running, and leaping; for what can we conceive permitting of a more easy springing carriage than that of an elastic arch? If a small arch was built of wedges having pieces of india rubber placed between each, it would resemble the mechanism of the foot.

In walking, we sway a little to one side, then to another, as the weight of the body moves from one foot to another; but were the leg inelastic, as when a wood one has to supply the place of a natural one, the lower part would have to be advanced in a kind of half-circle; from a slight bend of the knee, and the contraction and lengthening of the muscle, the leg can be moved straight forward, and thus the body more easily and steadily progresses.

Even this cursory and popular glance at the mechanical arrangement of the framework of the human being must strike all with gratitude that we are so "fearfully and wonderfully made;" still there are a few points that are worthy of attention, which have not yet been noticed.

A teacher of medicine in the sixteenth century was accused of promulgating doctrines contrary to a belief in the existence of a God, and sentenced to death; he repudiated the charge, and picking up a straw, said, "If there was nothing else in nature to teach me the existence of a Deity, even this straw would be sufficient." This beautiful and simply expressed truth did not perhaps strike his blinded bigoted judges in the manner it ought to have done; let us put aside many other important particulars, and merely examine the mechanical construction of a straw. It is well known that if a beam be rested on each end until it bends in the centre, the atoms of matter in the outer part of the curve are separated and held together by the general tenacity of the substance, and that the atoms of matter in the inside of the curve are driven closer together, while the atoms of matter in the centre of the beam, called scientifically the neutral axis, lie truly neutral, and may be removed without much damaging the strength of the beam. This, then, shews that a hollow piece of wood would be about as strong as a solid piece, and is one argument in favour of a straw being made in this manner. But if the material composing the stalk of corn were formed into a solid, it is palpable to the commonest understanding, that it would not have strength enough to support the invaluable head that it does so gracefully and securely. On this point it has been proved by Tredgold, that when the inner half-diameter of a

hollow cylinder is to the outer as seven to ten, it will possess twice the strength of a solid one of the same weight; arising from the substance being further from the centre, and therefore resisting with a longer lever. This, then, is conclusive of the wisdom of a hollow form to the straw; and from this reasoning originated the valuable improvement of hollow tubular bridges, resulting in the majestic structure across the Menai Straits. Another advantage which is important is the lightness of the tall column of straw and the economy of material, whilst its height allows it elastically to bend to the passing breeze without breaking, each part but gently feeling the power before which it has to bow, and consequently rising again uninjured. Besides these circumstances mentioned, the corn-stalk is formed with an outer surface of a hard material comparatively with that of the inside, and in many vegetable stems their forms are ridged, angular, and fluted. In describing the straw we have generally been describing the structure of the bone of the human frame; in one particular it differs, that is, as to rotundity; it possesses a hard outside in many places, most especially the teeth and spine, and the os humeri has ridges to give strength, and it is a tube; but the whole exemplifies lightness and economy of material, as in the straw. The hollow of the bones is filled with fine membranous cells that do not communicate with each other, and are filled with an oily substance called marrow. In some of the extremities of the bones that are expanded to increase the extent of surface at the joints, there is a thin compact substance that looks like a kind of honeycomb, as we see on breaking the bones of animals placed on our table as food. In the oblique part of the thigh-bone these are seen to converge to a point in the shaft, as if supporting the parts projecting from the centre of gravity. Hard as is the surface of a bone, yet it is penetrated by minute vessels that convey to it support to make up for any waste of substance and to renew its material; for the law of nature is, that during our passage from the cradle to the grave every atom of us shall be continually changing. These bony cells, called cancelli, also exist in broad flat bones; the outer surfaces, being named plates or tables, are strong and hard. The tough elastic substance called cartilage, that pads and defends the bones against friction, and fills up irregularities, making a smooth gliding surface, is of a milk-white pearly colour, and is always placed where firmness, pliancy, and flexibility are needed; and in the spine and foot these qualities so destroy the effect of concussions, that the body or brain does not suffer as it would if they were absent. The weight of the upper part of the body on the cartilages of the spine during the day compresses them, so that a person is taller on rising in the morning than on lying down at night. This compression has been found to be in some instances as much as an inch. The joints are tied together by strong unyielding cords called ligaments, that have a tenacity hardly to be found in any other substance. These hold the bones in their places, and restrict their motion to that appointed to each. The cartilaginous surfaces of the joints, to aid ease of motion and obviate friction, are smeared with the oily fluid before alluded to, which makes them perfectly slippery; this is commonly known as the joint-oil. It is secreted by appropriate glands, and confined to the parts where it is required by a very delicate membrane called the synovial membrane.

Bundles of minute fibres are joined together and form a muscle; their

cohesion is maintained by vital power: thus a powerful living muscle is weak and easily torn when dead. The faultless form of beauty in the human figure is preserved by the bulky muscles being connected with slender tendons, that make up for their want of substance by their dense and tough nature. According to the intended action of particular joints, so are muscles placed to aid by their mechanical power. The contraction of a muscle is towards its centre; hence it is so placed and shaped as best to contribute to this mechanical purpose; in some instances there is an increase of tendons to a muscle, in others an increase of muscles to a tendon. One of the muscles of the eyeball is a perfect pulley, and moves the eye in a direction contrary to that in which the force is applied. In fact, the whole of the muscular system is a beautiful adaptation of power to particular parts.

The size of the muscles depends much upon their exercise; thus the arm of the anchor-smith is thick and powerful from being brought into constant and great action; the leg of the ploughman is a mere straight shank from his preventing the action of the muscles by thick unbendable laced boots; thus the bluff brawny-shouldered man has calfless legs, and is ridiculed as spindle-shanked. The opera-dancers, who practise "the poetry of motion," have thick calves from incessant exercise of the foot and leg. The demoiselles of the capital of la belle France challenge the world to match their lower limbs, produced by their love of the dance and their daily indulgence in it: it has also been attributed in former times to the flagless parts of their city. This challenge may confidently be accepted by the fair sex in the towns of Newcastle-upon-Tyne and Gateshead, where there is not a level street, and therefore, as the inhabitants are ever either climbing up a hill or going down one, the muscles become well developed; while in Hull, where the town and country are a dead level, they would shrink from a contest with their sisters in Northumberland.

The strength of muscles by exercise is exemplified in the person of every one in reference to the arms, as from the habit of using more constantly the right hand the right arm is much stronger than the left. So negligent have society generally become, and so pernicious their fashions and systems of education, that diseases arise from the inaction and pressure on this grand contrivance of leverage for motion; and foreign governments have actually patronised institutions for the prevention and cure of many chronic diseases in youth, and of many morbid affections of adults, *by movements;* one of these establishments, which may be truly termed the anti-indolent and anti-fashion hospital, flourishes in the heart of the mighty, educated metropolis of Great Britain. All exercise should be moderate, gradual, and regular, like the training of a race-horse, but ought not to be excessive. When a prize-fighter trains, he takes moderately of porter, eats underdone beaf-steaks with an allowance of bread; he thus raises the power of his muscles to the utmost pitch for the occasion of his battle; but were he to continue this system, disease with its accompanying prostration would ensue. Dr. Arnott observes, "As animal power is exhausted exactly in proportion to the intensity of force exerted, there may often be a great saving of it by doing work quickly, although with a little more exertion during the time. Suppose two men of equal weight to ascend the same stair, one of whom takes only a minute to reach the top, and the other takes four minutes; it will cost the first little more than a

fourth part of the fatigue which it costs the second, because the exhaustion is in proportion to the time during which the muscles are acting. The quick mover may have exerted perhaps one-twentieth more force in the first instance, to give his body the greater velocity, which was afterwards continued; but the sloth supported his load four times as long. The rapid waste of muscular strength which arises from continued action is shewn by keeping the arm extended horizontally for some time: few can continue the exertion beyond a minute or two." Nevertheless the fakirs of India, where bigotry overpowers nature, will stretch out an arm and hold it in that position until the muscles become rigid and wasted, and the arm immovable.

The power of the muscles of man is far beyond that of any animal near his size; and there are instances of the capability of endurance of muscular fatigue and exertion almost incredible, and never equalled by quadrupeds. We have referred to the feat of Topham; and there was that of Carr the blacksmith, who lifted up a large anchor of a ship and carried it over the sands at the sea-shore to his workshop,—a weight that would have broken the back of a horse. This same man on one occasion laboured at his fatiguing employment during upwards of ninety hours without cessation. In consecutive days' journeys a horse cannot compete with a man; the former becoming exhausted, while the latter seems to add to his powers of continuance. The fatigue of walking a thousand miles in a thousand hours, uninterruptedly, and part of that backwards, is an act shewing a continuance of muscular exertion that no animal could sustain; and we suspect it would be difficult to meet with a quadruped, with all its advantage of length of leg for progressive motion, that could walk ten miles in one hour and twenty-two minutes;—yet such feats have some men delighted in accomplishing.

In bounding over a field full of hillocks, we find a great saving of muscular power by running down one side of a hill and up another; for the trifling quickening of the breathing is not equal to the continuance of exertion in going slowly down and up; the increased velocity gained in the descent carries us so far in the ascent, and we see this continually practised by those driving coaches.

Although not strictly within the scope of the present subject, still we think that as a summary of the most striking characteristics of the human body may awaken in some a spirit of inquiry, and in all a deep reverence for the divine power that could so wisely and with such love give to us such perfection of organisation, we state a few facts about the human frame. The prop-work, or skeleton, consists of 261 bones, weighing about 14 lbs., and is one inch less in height in the dead than in the living man; these bones are moved by 436 muscles. The mean weight of an Englishman is 151 lbs., and his height 5 feet 9 inches; the seat of mind, the brain, exceeds in weight twice that of any other animal; he tears and grinds the food that nourishes his body with 32 teeth covered by a substance nearly as hard as iron; he breathes 18 times a minute, and inhales in that time 18 pints of air, or more than 57 hogsheads in a day; every twenty-four hours he consumes 10½ cubic feet of oxygen, and gives forth, to feed vegetation, annually 124 lbs. of carbon; in infancy his blood pulsates 120 times per minute, in manhood 80, in age 60 times, and the weight of red fluid circulating in his veins is about 28 lbs.; his heart beats 75 times per minute, and drives at each

beat 10 lbs. of blood on its journey throughout the body; thus in twenty-four hours 12,000 lbs., or more than 24 hogsheads, pass through the heart, and 1000 ounces of this every hour visit the kidneys. Our breathing apparatus, the lungs, possess 174,000,000 holes, or cells, that would cover a surface 30 times greater than the body; 7,000,000 pores carry off the used portion of the human body, each of which is about a quarter of an inch in length; and thus there is a drainage of nearly 28 miles by means of small tubes, and 33 ounces of insensible perspiration escape in 24 hours—a fact sufficient to impress the mind with the importance of ablutions; the weight of the atmosphere borne by ordinary-sized persons is about 13 tons; and the average duration of man's life is, in towns 38, in the country 55 years.

It is a principle in mechanics, that if the size of a machine be in creased, its strength must be so also at the rate of the square of the increase; thus if it be made four times as large as before, its strength must be sixteen times greater; in doing so the weight is increased four times, the strength therefore sixty-four times. By progressing in this manner, the machine at length would actually crush itself by its weight. The same principle extends to man, and this is the reason why very tall men are generally a burden to themselves and exhibit weakness in the legs. From this law is seen the impossibility of giants: sorry are we to say so, as it will to many unsuspecting juvenile readers destroy the illusion of that favourite and enduring romance of *Jack the Giant-killer*, but we can assure them that the biographer of famous Jack himself created the giants before giving them up for the exhibition of the renowned hero's courage and cunning.

HYDROSTATICS.

THIS word is a Greek compound, and literally means *water*, and *to stand;* the branch of science to which it refers treats of the weight, pressure, and equal balance of fluids in a state of rest, also of the method of weighing substances in them.

Matter has three peculiar forms: solid, as the earth; liquid, as the ocean; and aëriform, as the atmosphere we breathe.

A fluid is a body that yields to any impression; the atoms of matter of which it is composed gliding among each other with such ease, that they do not combine, as solids, into distinct forms, but take the shape of any vessel in which they may be placed. Thus, both the liquid and aëriform kinds of matter are termed fluids. Water may be turned into the aëriform state of invisible gases, and then reconverted to its former liquid condition, palpable both to the eye and touch. When water is in the form of steam, the atoms of matter seem as if they separated to a great distance, and were floating in a large elastic atmosphere, their former attraction being lost. If water be poured into a ladle heated to an intense degree, the attraction is not lost, nor does it take the form of steam until the ladle has cooled down to a certain degree. When becoming ice, water increases in bulk, and the atoms seem to adhere closely together.

Fluids are said to be elastic and non-elastic; by which it is meant, that some cannot be compressed into a smaller bulk, as water, oil, mercury, and

alcohol; while others are compressible into a smaller space, as air, steam, and gas. This is not strictly correct, for those which were at one time thought to be incompressible are now discovered to be slightly so. Another distinction is sometimes made in calling the first liquids, and the latter fluids; defining the difference to be, that non-elastic bodies, or liquids, have not an immediate tendency to expand when at liberty, which elastic bodies, or fluids, have,—in fact, occupying in their aëriform state somewhere about two thousand times the space that they do when forming part of a liquid or solid. In all the variable positions which matter may assume, whether solid, liquid, or aëriform, the atoms of which it is constituted never lose their individual properties.

Neither the form nor size of the atoms comprising water are known, but they must be very minute, as they penetrate the substance of most bodies, pass up the small tubes of fibrous productions, and float in the atmosphere as mist and clouds. They are generally admitted to be globular.

It does not then appear that fluidity arises from the shape of the particles of water, but from *the imperfect cohesion of the atoms.* Some fluids have more tenacity than others, as tar, honey, oil, which are viscous and imperfect fluids in comparison with water, mercury, and distilled spirits.

Solids have a centre of gravity, and, bound by attraction in a body, fall with great force. If the air were withdrawn, a mass of water would fall with the like effects: but fluids have less attraction among their atoms, and their easy separation causes them, when in small quantities, by the resistance of the atmosphere in falling from a height, to form into small drops or globes, with all the lightness that a solid piece of timber reduced to sawdust would fall if poured from an elevated place.

THE PRESSURE OF FLUIDS EQUAL IN ALL DIRECTIONS.

Solids, from attraction, are pressed downwards toward the centre of the earth, and water obeys the same universal law.

But there exists this difference and peculiarity in fluids as compared to solids, that a body of water or other fluid being acted upon by a force in any one direction, presses upwards, sideways, and in every direction, equally with the same force from the same point.

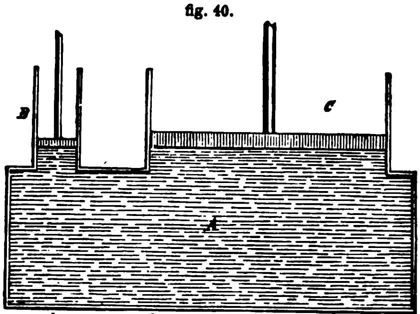
If a bladder be filled with air or water, and tied at the neck, then pressed upon, not only will the parts underneath the weight be compressed, but every other part of the bladder equally, all offering a reaction or resistance to the weight. This may be proved by making a small puncture at the farthest point from the pressure, when the air or water will issue out with force.

The upward pressure of water may be seen on plunging the hand into a jar of water, when the water will rise upwards; or in attempting to put a cork into a bottle which is filled to the brim with liquid.

That it presses equally may be proved by a simple experiment. Let A be a close vessel filled with water, having two tubes, B and C. Say that B will admit a cork measuring one inch in area, into which a stick is fixed as a piston, and C admits a bung measuring ten inches in area. By pressing upon the piston at B with the weight of one pound, the bung at C is pushed up with a force of ten pounds; for every square inch in the vessel is acted upon with a force of one pound. Thus, a small quantity

of water confined in a space having a slight pressure on its surface may act as a mechanical power with a force equal to hundreds of pounds. If the tube B hold a pound of water, and it was poured in, the cork having been withdrawn, the same results would take place as when a pound of pressure was applied to the cork. But for the bung to rise one inch, the cork must descend ten inches.

fig. 40.



Again, suppose that there was only one tube, measuring ten inches, and a 100lb. weight was applied, and a hole made in the side or bottom of the vessel of the same size as the tube, the water would rush out if not kept in by a force equal to 100lb. Thus it shews that the pressure at the bottom or sides is equal to that at the surface; in short, acting in all directions.

PRESSURE OF WATER ON THE BASE OF ITS CONTAINING VESSEL IS IN PROPORTION TO ITS HEIGHT AND BASE.

If a vessel in the form of the diagram be filled with water, the bottom of it does not have pressure equal to the weight of all the water it contains, but only as if there was a column of water the same size as the bottom of the vessel which rose up to the top. Now, if the vessel was turned up, and had a bottom as broad as the top, and a top as narrow as its base, then the pressure on the broad bottom would be as great as if the vessel were as wide at the top as at the bottom. In this case, the upright column which we pointed out in the other form of the vessel presses sideways as well as downwards, and thus an equality of pressure on the base takes place.

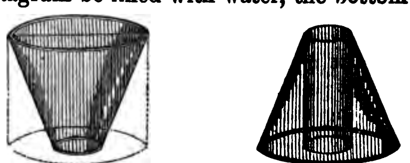


fig. 41.

From the above facts, and that the small quantity of a pound of water is capable of producing a pressure of thousands of pounds, arises what is commonly called the *hydrostatic paradox;* meaning something wrong or absurd. Now there is nothing in this branch of science but can be shewn to be governed by certain positive laws, as capable of accurate calculation as the powers of the lever or pulley in mechanical science.

A SMALL QUANTITY OF FLUID MAY BALANCE A LARGE QUANTITY.

The *hydrostatic bellows* is the usual mode of exemplifying this truth; and it clearly demonstrates the upward pressure of water.

Suppose two boards, each measuring 18 inches one way and 16 inches the other, were joined together by leather or gutta percha, perfectly water-tight, in the same manner as a pair of common bellows; then a pipe 3 feet long be added, communicating with the bellows, which pipe, when full, will hold about a quarter of a pound of water. On the top of the upper board place a 300lb. weight, and pour water into the small pipe,

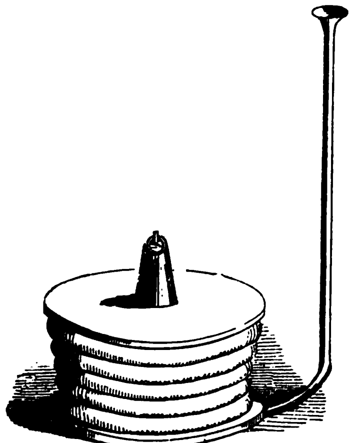


fig. 42.

when it will run in between the boards and raise the weight; by continuing to pour in water, the boards will be raised to the extent that the leather or gutta percha will permit them to separate, and the little stream of water that remains in the pipe, weighing a quarter of a pound, will about balance the 300lb. weight, the water not being forced by the great pressure out of the pipe. A person may stand on the bellows, and blow into the pipe, when he will raise himself up, and, by placing his finger on the top of the hole, sustain himself thus elevated with perfect ease. This is on the same principle as the steelyard, or other long lever, where a small weight at the end of the long arm balances a much greater weight at the short arm.

Experiments have been tried on strong casks, having a tin tube twenty feet long fixed to them, water being poured in until they were filled, and it rose to within a foot of the top of the tube, when the casks burst with immense force.

These experiments resemble those in mechanics, where a small weight descending a long way in any given time, is equal in effect to a great weight passing through a short space in the same period of time. By increasing the length of a tube, and filling it with water, a pressure may be created to almost any extent. In the cases we have mentioned of the bellows and the casks, it may simplify the reason of such results by pursuing the subject a little further. If a pipe, exactly the same size as that used to pour in the water, was inserted in another part of the bellows or cask, the water would rise in it exactly the same height as it stands in the supplying pipe: if a dozen or more tubes were inserted, the same thing would occur in every one of them. If a hole were made the same size as the bore of the pipe, holding the quarter of a pound of water, and the finger were placed upon it, a pressure equal to that of a column of water the same height as that in the tube would be felt; and if fifty or more holes were made, every one would offer this amount of resistance. Thus, on every portion of the inner surface of the cask or bellows of the size of the bore of the supplying pipe, there exists a pressure equal to the weight of the water it contains; and by multiplying the number of times that the size of the bore covers the surface by the weight of the water in the tube, the amount of pressure is ascertained.

In the bellows, which we cited as an example, one quarter of a pound of water in the pipe sustained 300 lb., or 1200 quarters of a pound; the area of the top of the bellows must therefore be 1200 times that of the pipe conveying the water. As the bore of the pipe is diminished, and its length increased, so is the power of raising a weight multiplied. Now suppose the bellows were filled with water, and then a pipe screwed on 3 feet high, the water would only stand in the pipe to the same height as that in the bellows; place weights upon the bellows, and the water would

rise up in the pipe, and on the bellows we mentioned the weight would have to be 300 lb. before the water would reach the top; lengthen the tube, and the weight would have to be increased. As it is a truth that 1000 ounces of water (or $62\frac{1}{2}$ lb.) is a cubic foot, the weight of water can be ascertained in pounds.

The *hydrostatic press*, invented by Mr. Bramah, is one of the most useful and powerful applications of this principle. It is used by printers and paper-makers to give smoothness to the paper, and by dealers in light goods to compress their articles into a small space for transit; also as a machine for raising weights.

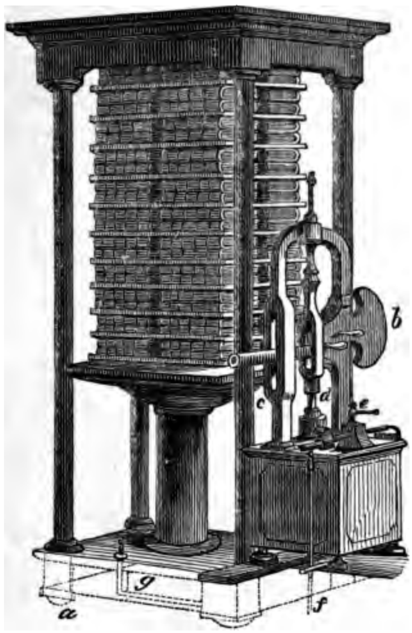
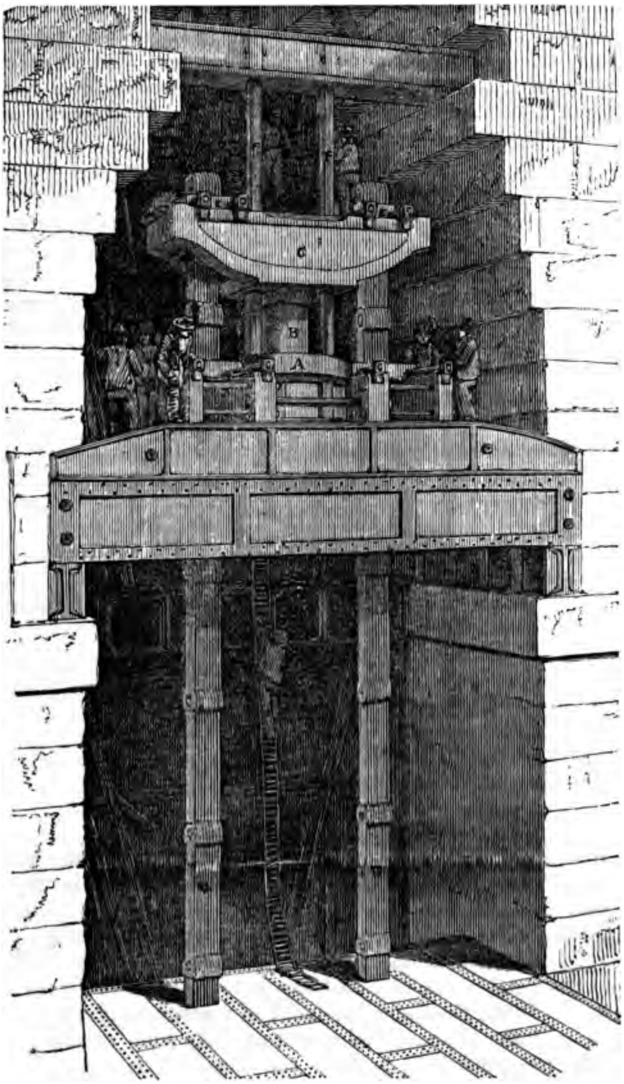


fig. 43.

d is a small forcing-pump, in a small tank, to drive the water into *g*, which is a stout cylinder. A closely-fitting piston in the centre moves freely upwards and downwards, but allows no water to escape; on forcing the water into *f*, the piston is driven upwards. *b* is the handle or lever by which the pump is worked; and *a* the pillars for supporting the entablature, and enabling it to resist the upward pressure of the piston. When the desired amount of pressure is given, a stop-cock *e* is turned, and the piston remains at rest. As soon as the articles are supposed to be sufficiently pressed, the stop-cock is turned back, and the water flowing out, the piston gradually descends. Now, in this machine the pressure that is available is that on the bottom of the piston, and the force employed is the pressure on the water at the bottom of the piston in the pump; the power employed will therefore be to the effect produced as the area of the base of the small piston in *d* to the area of the

piston g; but as the areas of circles are proportional to the squares of their diameters, we may thus illustrate our subject: suppose a force of 50 lbs. to represent the pressure under the piston d, and its diameter two inches, the



The Hydrostatic Press used to raise the tubes of the Britannia Bridge.

diameter of g being 20 inches, the pressure on g is found thus: $2^2 : 20^2 :: 50 = 5000$; or $4 : 400 :: 50 = 5000$, the pressure on the bottom of the piston g. When the bore of the pump is very small, and the power great that is ap-

plied, the force amounts to hundreds of tons. The pump in this case acts instead of a long tube, containing a small column of water.

Two of these machines were employed by Mr. Stephenson to raise the immense tubes of the Britannia Bridge from the Menai Straits to their proper elevation. Those used were the most powerful ever constructed, weighing forty tons each. The sides of the cylinder were eleven inches thick, and its weight was sixteen tons. The piston was twenty inches in diameter, and the pressure upwards of eight thousand pounds per inch! One press was perfectly competent to raise the tube, 1800 tons, although two were used. The pipe, through which the water was forced into the cylinder, by means of a steam-engine, instead of the power of a man pumping, was made of cast-iron, and only a trifle more than an inch in diameter, and its bore about half an inch. During the operation one of the pumps burst, upon which the skillful engineer made the bottom of the cylinder of a more rounded shape than it had on its first construction; by so doing, the pump proved capable of sustaining the immense pressure to which it had to be subjected. Such was the force with which the water was driven into the cylinder, that it was calculated to move a jet to a height of nearly 20,000 feet, which is more than five times as high as the top of Snowdon, 5000 feet higher than the summit of Mont Blanc, and nearly fifty times higher than the top of St. Paul's in London.

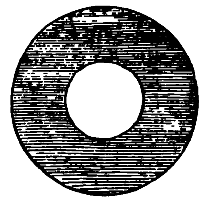


fig. 45.

PERPENDICULAR PRESSURE AS TO DEPTH.

In solids, the lower atoms of matter support those placed upon them, as the foundation of a house bears the whole of the lofty pile above. The same rule extends to fluids, every layer of atoms having to bear the weight of those resting upon them.

The weight of solids is estimated according to their size or quantity, but the pressure of fluids is as to their perpendicular height; hence, to estimate the pressure, the area of the base is multiplied by the perpendicular height and the density of the particular fluid. Thus, then, if water be in a vessel that slopes from the bottom to the rim, the pressure will gradually decrease as it approaches the top, for every upward line of atoms acts as a separate column sustaining its own weight.

If a tube, one inch square in the inside, and two feet long, having a flap at the bottom, attached at one side by a hinge, and at the opposite having a cord passing over a pulley, with a weight hung from it, be filled with water; it will be found that this column, two feet high and one inch square, acts with a force of nearly one pound; so that we may generally say at any depth, every two feet of water presses on the side or bottom of a vessel with a weight of one pound on every square inch.

The effect of the increase of pressure as to depth is exemplified in the wrecks of vessels near

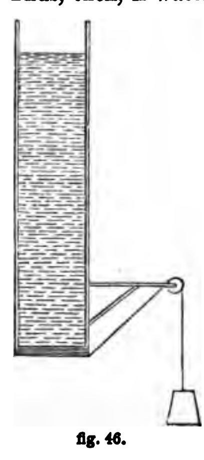


fig. 46.

the coast where the water is shallow; there they float to the surface, and are cast on the shore; whereas in such a supposed case as that of the unfortunate *President* which, going down in deep water, the pressure was so great that the water filled the pores of the wood, which became so heavy that not an atom of the wreck floated to the surface to point out the spot, or as a memento of its fate.

If we watch a bubble of air or steam rise from the bottom, we shall perceive it start on its upward journey as a little silvery bubble; but as the pressure becomes less, the size increases, until it bursts or rests at the surface.

At ten fathoms depth, a strong, square, empty glass bottle will be crushed to pieces.

A living man can only descend to a certain depth, as the pressure of the water upon the elastic air in the chest is such as would speedily cause death.

As fish are only found near to coasts and in shallows of the ocean, it is supposed that a light atmosphere of water is more suitable to them than the density of the deep valleys of their natural element.

LATERAL PRESSURE.

Fluids act in all directions, pressing downwards, upwards, and sideways. The force that water acts on a square inch of surface one foot deep is seen to be $\frac{1}{2}$ lb., on two feet 1 lb., on three feet $1\frac{1}{2}$ lb., on four feet 2 lb., on five feet $2\frac{1}{2}$ lb., on six feet 3 lb., and so on.

But in lateral pressure there is this to be taken into account, that as it presses against the upright sides less at the top than at the bottom, to find the amount of pressure we must balance the account, and the true force against the whole side will be found to be that which acts on the middle part, half-way from the top and bottom, when the sides are perpendicular.

Now, if we take an open square vessel full of water, say twelve feet deep, the pressure on the bottom will be 6 lbs. per square inch, equal to 864 lbs. on a square foot, and the pressure on the side half-way down, that is six feet from the top and bottom, is exactly one-half, or 3 lbs. on a square inch; because the six feet is just one-half the depth of the water at the bottom, and what is wanting above the six feet in pressure is made up by the greater stress below, hence an average pressure on the whole side results. The lateral pressure then is 432 lbs. on each square foot of the side.

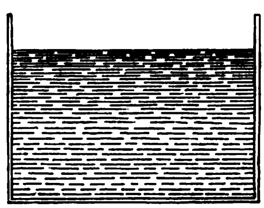


fig.47.

The extent of the breadth or length of the water makes no difference in the pressure, whether it only be a foot or miles; all depends on the extent of the side acted upon, and the depth of the fluid.

It is a knowledge of this law of nature that enables man to erect gates and banks by which he can shut out the ocean, as is done in many maritime ports, and in Holland; to keep out the whole body of a river by a coffer-dam, while he sinks a foundation and builds the buttress of a bridge; and to carry canals over mountains by means of gates: for an erection requires no more strength from having a sea pressing against it,

than if it were a small quantity of water of the same depth; of course in saying this we do not take into account the force of the sea when agitated and driven with impetuosity against the erections intended to resist its encroachments.

When the interests of man require him, for some structure, to sink a firm foundation on a surface covered by water, he commences his operations by driving two rows of beams or piles into the mud or gravel, then between these he batters down clay—this is technically called puddling; having formed this temporary wall, the water is pumped out of the enclosed part, concrete laid down, and building proceeded with.

In the figure here given, by rows of piling *b b*, *c c*, enclosing a certain amount of space, the foundation *a a* of a pier may be built, the water being previously pumped out from within the space; the pressure on the piles *c c* is proportioned to the depth of the water *f f*.

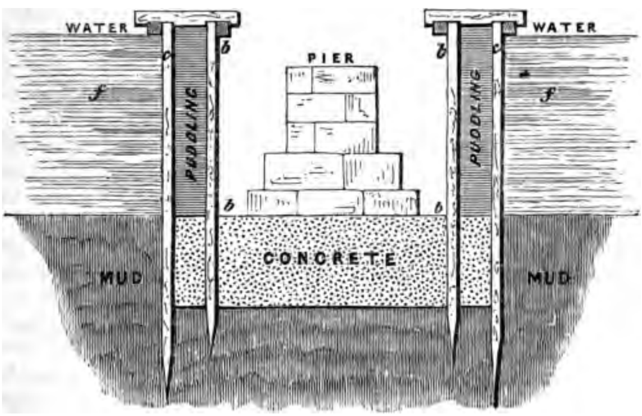


fig. 48.

If it be wished to know the pressure on the sides of a vessel intended for holding water, the manner of doing so is first to find the area of the sides; suppose it to be 12 feet deep and 20 feet circumference, multiply 12 by 20=240, then multiply this product by half the depth 240 × 6=1440, and this gives the number of cubic feet of water, the weight of which presses against the sides; then, as before stated, a foot of water weighs 1000 ounces, so that the amount of pressure is 1440 × 1000= 1,440,000 ounces, or 6000 ounces on a foot.

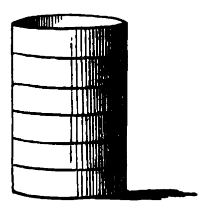


fig. 49.

It was the knowledge of the pressure of fluids that caused the idea to be entertained of forming a ship-canal across the isthmus which joins North and South America, and of stemming out at one side the North Pacific, and on the other the North Atlantic Ocean, with as much ease as forming dock-gates at Sunderland or Southampton. Were this law not in existence, the banks of the sea would soon be swallowed up by the mighty ocean; and it makes evident the practicability of recovering much valuable land now covered by the sea.

In the adjoining figure A B is supposed to represent a tall vessel full of water and kept so; from the centre is drawn a semicircle: three perpendicular lines, *d* 3, *c* 1, *a* 5, are also drawn, the lower and uppermost being at equal distances from the centre one. When the plug is taken out of the centre spout, the water flies as far as M, and the distance N M is double *d* 3; but from the spouts *c* and *a* the water only reaches to K, and N K is double *c* 1 or *a* 5.

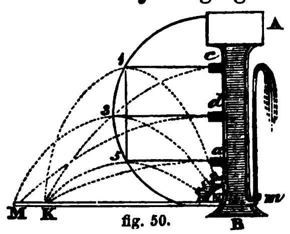


fig. 50.

Thus then the rule is learned, that the horizontal distance to which a fluid will spout from a horizontal pipe in any part of the side of an upright vessel below the surface of the fluid, is equal to twice the length of a perpendicular to the side of the vessel, drawn from the mouth of the pipe to a semicircle described on the altitude of the vessel.

Plug up the three spouts, and open those placed obliquely at the bottom, saying they are placed at angles of $22\frac{1}{2}°$, 45°, and $67\frac{1}{2}°$, and it will be seen that the streams issuing from them will cut the curve-line in those places to which the lines were drawn. That in the centre being at 45° sends the water to M as it did from the centre horizontal pipe; and as the other two streams only reach K, it throws the water the greatest distance. In the notice of projectiles we stated the law of curvilinear motion, which the above streams obey as exactly as bodies thrown by other forces.

As the pressure of fluids depends on the depth, it shews the necessity of having embankments broader at the bottom than the top, the hoops of vats closer and stronger near the base, and the forming of canals no deeper than necessary to float the vessels that have to be the means of the transit of goods or passengers.

At a thousand fathoms depth of the ocean, the water is more dense or compressed in its bulk by the one-hundredth than it is at the surface.

EQUAL PRESSURE.

As air presses equally on all parts of the human body and other substances, so does water on any substance immersed in it; thus, if a piece of cork be sunk a great depth, it will retain its former shape though its size be decreased; this is from the equality of pressure on all its parts; or if a piece of soft wax be inserted in a bladder of water, and a great weight placed upon it, the wax will not be changed in form, from the pressure of the water being equal on all sides.

The pressure of water laterally and downward has been exemplified, and the pressure upwards is seen by its rising in any hollow tube placed in water. This is commonly illustrated by means of a tube, at one end of which is placed a piece of lead which fits closely but is not fixed; a piece of string holds the lead in its place until the tube is sunk a certain distance, when that is let loose, and the lead is then found to be sustained by the upward pressure of the water. Water poured in at the top, or allowed to ooze in at the bottom, causes the lead to fall, for then there is a downward pressure; and as the lead is heavier than the water, it falls immediately.

If a vessel be deep in the water and unfortunately springs a leak, from

upward pressure the water rushes in with all the force of a column of water the size of the hole and the height to the water-mark. As the vessel becomes fuller and settles down nearer to the height of the water outside, the force of flowing in weakens with the approaching fate, and ends with the last feeble drop that consigns it to a watery tomb.

If two pieces of wood be made so that their surfaces fit closely, and one of the pieces be fastened to the bottom of a vessel, then water be gently poured upon them, the upper loose piece will remain at the bottom, because the water presses down upon it; but if it be in the least raised, so as to allow the water to insinuate itself between, then it rises to the surface, because there is an equality of pressure, and the wood being lighter than the water, it at once floats.

The immense power of a small stream of water is one of those means which nature uses to rend mountains, be they of yielding earth or stubborn granite; a small quantity insinuated into a crevice brings down the towering cliff of hardened rock in fragments to the valley beneath. Thus, if a cavity *b* in the face of the hill *a a* has no outlet, but is supplied with water through the fissures *c c*, the face of the hill towards *d* will be forced outwards, on the cavity *b* filling, with a power proportioned to the height of the fissures *c c* and the interim surface of the cavity *b*.

fig. 51.

If a strong wall of masonry *b b* be erected to hold up a butting in the earth *c c*, and proper holes *d d* be not left to drain off the water that may accumulate behind, they will be cast down, unless built with a strength calculated on the same principle as a lateral pressure, having to sustain that weight of water; in fact, as an engineer would estimate a dock-gate.

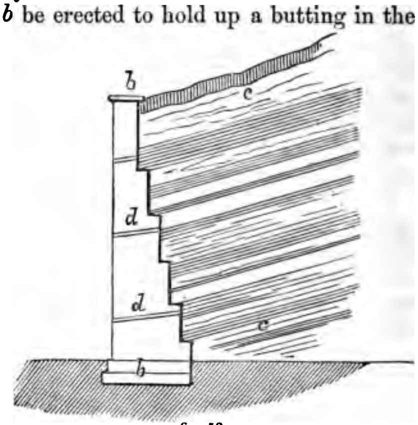


fig. 52.

In many parts of London, during an extra high tide or much rain, drains will burst, and throw up the pavement as if a slight earthquake had taken place, which arises from the drains becoming choked, and the pressure of the water heaving up the superincumbent mass.

LEVEL SURFACE OF FLUIDS.

Every atom of fluid being attracted to the centre of the earth, and having an independent gravity, its surface becomes a perfect level to the face of the earth.

But as the earth is not a true level from being a sphere, neither is water; as may be seen when watching a vessel sailing from a shore; the

hull disappears first, then the lower parts of the mast, and gradually the entire is lost to view; when first seen approaching the land, the pennant comes into view, then the cross-trees, the deck, and the hull. Nevertheless, what is understood by a dead level, means that every particle is at an equal distance from the earth's centre. The only variation from this arises at the equator, where the water is further from the centre of the globe than that which is at the poles, caused by centrifugal force, from the quick rotation of the world. Some high mountains likewise cause the waters to be affected in their natural level, as they are powerful enough to create a lateral gravitation, as illustrated in a small body hung near the side of a mountain. Winds and currents also, in some parts, have the effect of raising particular waters, as in the Red Sea, which is 32 feet higher than the Mediterranean, and the Pacific at Callao, which is 23 feet higher than the sea at Carthagena.

Were a true, or apparent level, as it is termed, taken on the earth's surface, it would be found that at every mile it was 7 inches and 9-10ths higher than a natural or dead level; this, then, demonstrates that the bend of the earth is nearly eight inches a mile.

When railway engineers proceed to set out their lines, they have attached to their instruments a small glass tube, called a level, filled with spirit, except one bubble of air, and when the air is an equal distance from both ends, their theodolite is level: they then look through a telescope, or sight-hole, at a pole having figures or lines upon it, which has been placed at a measured distance—say of a mile; the figure which the sight-hole cuts across is then noted, and for the convexity of the earth 7 inches and 9-10ths are allowed off, which gives the dead level. In forming a canal, were the same rule not observed, and a true level used instead of a dead one, the water would all rest at one end, for in three miles it would have to ascend from the surface of the earth nearly two feet. A fall of three inches per mile gives a motion to a stream or river of about three miles per hour.

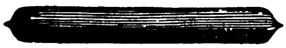


fig. 53.

Water seeking its level is the cause of many of the changes that occur on the surface of the earth; for as "streams their channels deeper wear," they carry forward the substance and deposit to the ocean, ultimately forming new and extensive land for the habitation of man. Water seeking its level grinds down rocks, washes away mountains, leaves bare or fills up lakes, and thus makes the surface of the earth a smooth plain, luxuriant and not perniciously humid for the family of man.

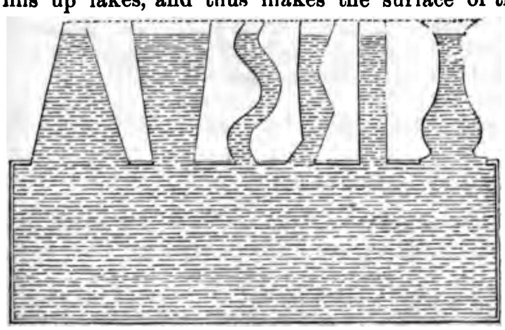


fig. 54.

Whatever may be the size or shape of tubes fixed into a vessel, if any one of them be filled with water, it will rise to the same height in each. Thus if the first one have water poured in until it rises to the dotted line, it will be found every

one is filled up to the same level; and if the part which joins the vessel be in all of them the same size, the same pressure on the bottom must result, as has already been explained. If a glass tube reaching the bottom of a cistern be run up the outside, the exact height of the water in the vessel may readily be seen. Hence water seeking its level is one of the most important benefits to man in his social arrangements, for by taking advantage of this law of nature he places pipes to water which is at an elevation, lays them through any inequality of surface, buries them underground, rears them to the top of his highest buildings, and thus has the valuable element ever ready at his will.

SPECIFIC GRAVITY.

To Archimedes we owe the discovery of the important and simple principle of determining the specific density or gravity of different substances. A king of Syracuse, suspecting that a crown of gold he had ordered did not contain the amount stated of the precious metal, employed Archimedes to solve the problem. The philosopher for some time was puzzled, until one day, being in his bath, he observed, that as his body sank, so was the water displaced. His master mind instantly saw that bulk displaced so much water, yet that the weight of his body in less size would not produce the same effect. This dawn of truth, he perceived, would lead to a solution of the king's question; and, in the ecstasy of the moment, he leapt from the bath and ran naked through the streets, shouting, "I have found it! I have found it!" He then got a mass of gold of the same weight as that given to form the crown, and weighing the gold and the crown in water, he found that the gold weighed much heavier than the crown. Next, he placed the gold carefully in a vessel filled to the brim with water, and accurately noted the quantity of water that flowed over; refilling the vessel, he placed in the crown, and found that a much greater quantity of water was displaced than by the mass of gold, consequently that some lighter metal than gold had been mixed with it, which increased its bulk.

If an empty glass tube, closed at both ends, capable of holding a pound of liquid, be immersed in water, it will require a force of one pound to hold it under water, and if filled to the brim, there will run over exactly its own bulk. Thus, then, this is proved, that the pound of displaced water was supported by other atoms of its own body with a force of one pound. But if the tube were filled with quicksilver, or any other heavy substance, and weighed, after which it be plunged into water, it will be found to weigh one pound less than on being weighed in the air. Thus, then, the bulk displaced of water sustains the weight of any substance equal to that bulk; and as any thing is lighter or heavier than

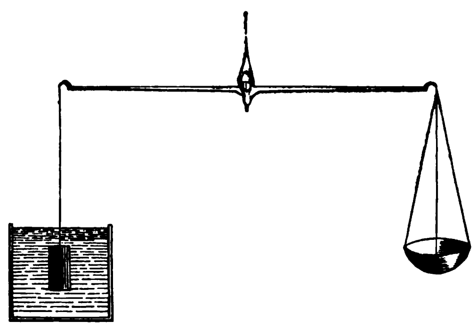


fig. 55.

the quantity of water displaced, so will it sink or swim. Another method of shewing that a body when immersed in water loses a portion of its weight equal to that which it displaces of water, would be, to hang the glass tube at one arm of a scale, or hydrostatic balance as it is called, and beneath it a heavy substance exactly fitting into it; then weigh these; after so doing, immerse the heavy substance in water, when the scale, with the weights, will sink down; fill then the glass tube with water, and the scale will exactly counterbalance as before. The water in the tube and that displaced by the heavy substance will be exactly the same.

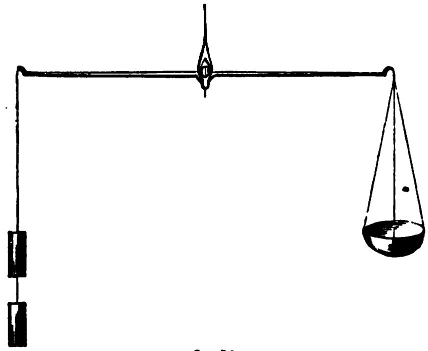


fig. 56.

Now, a pint of water weighs 20 ounces; a pint of lead about $13\frac{1}{2}$ lb.; and a pint of quicksilver about $17\frac{1}{2}$ lb.; the lead, in comparison with the water, being eleven times, and the quicksilver fourteen times heavier than the water, or possessed of this much more specific gravity.

To have a standard whereby one thing may be compared to another, philosophers have adopted that of water; as a cubic foot of pure water, at 60 degrees of Fahrenheit's thermometer, in all parts of the world, weighs 1000, and a cubic foot of quicksilver 14,000 ounces.

The rule is, "weigh the body first in air—that is, in the common way; then weigh it in water; observe how much weight it loses by being weighed in water, and by dividing the former weight by the loss sustained, the result is its specific gravity compared with that of water." Thus, if a guinea weighs in the air 129 grains, by being immersed in water, it weighs only $121\frac{3}{4}$; divide then the 129 by the lost weight $7\frac{1}{4}$, and the result is nearly 18; thus it is said guinea-gold is nearly eighteen times heavier than water. If the specific gravity were 18 or more, then the gold would be very fine; but if 17, or less, then it would be too much alloyed, and not worth the standard price.

If a piece of glass weigh 6 ounces, upon being immersed in water it will be found to be but 4 ounces, having lost 2 ounces of its weight; thus, then, $6 \div 2 = 3$, which is the specific gravity of the glass; or, we may say, that as much water as glass in bulk weighs 2 ounces, and as the glass weighs 6 ounces, which is three times 2 ounces, the glass is three times heavier than water.

16 ounces of iron, when weighed in water, will lose about 2 ounces; then, dividing the sixteen by two, the quotient will be eight, which is the specific gravity, iron being eight times heavier than water.

This weighty material, from being more enduring, occupying little space, and presenting less friction than wood, is now much employed in the construction of boats, barges, and ships. The floating properties of this heavy metal are produced by its being beat out into sheets, and formed into a large, hollow body. Presenting a great bulk for the resistance of the water, much lighter than the bulk of water, it consequently floats, and

can thus safely be loaded. But if there be as much weight placed in the iron vessel as that its own weight and its lading would be as heavy as a bulk of water the same size as the ship, then it would sink.

The same principle applies to vessels constructed of wood; and from the quantity of water a ship displaces, is known the weight of the vessel and its cargo.

When articles are weighed in water, it is usual to suspend them from the scale by hair, as that substance is the same specific gravity as water, and does not absorb the liquid.

In weighing bodies lighter than water, a weight is attached to them to cause them to sink, and allowed for afterwards in the calculation. Thus, if a piece of wood weighing 660 grains have attached to it a piece of metal of 480 grains, these two substances, when weighed in the air, will be equal to 1140 grains. Suppose in the water the wood and metal be found to weigh only 138 grains, then 138 taken from 1140 leaves 1002, the difference between the weight of the substances in air and water; but the loss of the metal in water was 50 grains; therefore the loss of wood was 1002 less 50, equal to 952. Now 660 grains, the weight of the wood in the air divided by 952, which it lost in water, leaves a decimal of ·694; then, the standard weight of water being 1, the wood is ·694, or nearly seven-tenths of 1; that is, a cubic foot of water is to a cubic foot of wood as 1000 to 694, for the one weighs 1000 ounces, and the density of the other is 694 ounces.

Various methods are used in ascertaining the specific gravities of substances that would be destroyed by being placed in water, as by placing them in phials, coating them with wax, &c.

The specific gravity of fluids is generally ascertained by means of instruments, named the gravimeter, areometer, and hydrometer.

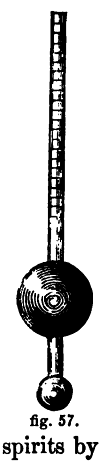


fig. 57.

The hydrometer is made of brass, ivory, or glass, as may be suitable to the uses for which it is intended, The narrow upper part has a graduated scale upon it, and the lower part is filled with quicksilver, or some heavy substance, to keep it upright. The bulb of glass loses 1000 grains when weighed in water, and as the action of the instrument is founded on the fact that solids of a given weight sink deeper in light fluids than in heavy ones, as this sinks, say to twenty on the scale, then the specific gravity of the fluid is said to be 1020. This instrument is used by government officers to ascertain the strength of spirits; for if it sink below a certain mark, the spirit is said to be above proof, and if not far enough, the spirit has been too much diluted.

By proof spirit is meant pure spirit, composed of an equal number of atoms of alcohol and water, which, on being poured upon gunpowder, will burn all away, and then the powder be set on fire and dissipated in a flash; but if the spirit be not good, the powder will become so wet that it will not fire. Others test spirits by pouring in oil; if the oil sink, the spirit is then proof.

A shopkeeper in China, says Dr. Arnott, sold to a purser of a ship a quantity of distilled spirits according to a sample shewn; but, not standing in awe of conscience, he afterwards, in the privacy of his storehouse, added a certain quantity of water to each cask. The spirit having been delivered on board, and tried by the hydrometer, was discovered to be

wanting in strength. When the vendor was charged with the intended fraud, he at first denied it, for he knew of no human means which could have made the discovery; but, on the exact quantity of water which had been mixed being specified, he was so confounded that he confessed his roguery, and made ample amends. On the instrument of his detection being afterwards shewn to him, he offered any price for what he foresaw might be turned to so good an account in his trade.

In ascertaining the specific gravity of gases, a copper or glass flask, having a stop-cock, is used. The flask, filled with common air, is carefully weighed; after which, by means of an air-pump, it is rendered perfectly empty and again weighed; the gas being admitted, its weight is ascertained, from which is deducted the weight of the empty flask; then the weight of the gas being divided by the weight of the atmospheric air, the result will be the specific gravity of the gas. In this instance the air is reckoned as 1000. But when compared with water, the flask is filled with that liquid, and compared as in the instances already given.

In the following table water is considered equal to 1000 ounces avoirdupois, and the specific gravities, given in round numbers, shew how many thousand ounces are contained in a cubic foot of the different substances named:—

Platinum . . .	22½	Stone, Common .	2½
Gold . . .	19¾	Salt . . .	2
Mercury . . .	13½	Brick . . .	2
Lead . . .	11	Ivory . . .	1
Silver . . .	10½	Beef Bones . .	1½
Copper . . .	8¾	Milk . . .	1
Iron	8	Sea-Water . .	1
Tin	7¼	Oak . .	9-10ths.
Zinc . . .	7	Alcohol . .	8-10ths.
Antimony . .	6¾	Ether . .	3-4ths.
Rubies, Eastern .	4	Cork . .	1-4th.
Diamonds . .	3½	Atmospheric Air	1-800th.
Glass, Flint . .	3	Hydrogen Gas .	1-1200th.

The support that bodies receive from the upward pressure of water is well known to all who have frequented the banks of rivers, or been much on the sea. The anchor, when parted from the bottom, is raised with comparative ease until it comes above the water, when a much greater strain has to be used to "bring it home." On the divers employed in recovering the remains of the *Royal George* meeting with heavy weights at the bottom of the sea, they moved them with comparative ease to apply the tackle; but when landed, the same weights were beyond their strength to raise in the slightest degree. It is from this support given to great weights that huge stones, laid as breakwaters, piers, and lighthouses, will be cast to great distances, as if but gravel. A person, by laying himself flat on water, and having his chest distended, feels no weight from his body, and he floats as easily as most substances; as, with the air in his chest, like the air in a fish, he is lighter than water. It is a pity that this truth is not more generally known, as many lives might thereby be preserved. If we watch those accustomed to swimming, they will often be seen to enter a river or the sea, and positively walk about, without more trouble or exertion, than when upon land; their whole secret consisting in keeping the face turned upwards, by which the chest is distended, and as much of the body as possible under water.

Bathers will hobble with pain to their naked feet over a shore covered with shingles, but on entering the water the difficulty ceases, and they walk about with perfect ease on the awkward sharp stones : this is from the water buoying up the body, and little pressure of the feet acting against the stones. Broken earthenware and glass is even passed over almost with impunity. If the body be greatly immersed, the feet are floated to the top, and the person has to regain the use of them as he best can. Sea-water, from being specifically heavier than fresh water, gives greater buoyancy to bodies, to the extent of one thirty-fifth ; this renders swimming in the sea much easier to man than in fresh water.

If a ship be deeply loaded in a fresh-water river, it becomes lighter on entering the sea ; but if the ship be deeply loaded in a port where sea-water floats it, and afterwards enter a river of fresh water, then there is danger of the ship sinking.

In the wonderful dispensation of Providence, an exception to a general rule exists as to water, and also in the baking of clay, in regard to the effects of heat. Thus we have seen that heat dilates substances, and cold contracts them ; but in water, the contraction proceeds only down to 40 deg. of temperature, from which point to that of freezing it again dilates, and, as ice, becomes lighter. From this watchful and preservative love of animal life, ice floats, keeping the water beneath fluid, and sufficiently warm for the existence of the numerous tribes that dwell in the liquid atmosphere. This singular adaptation in wintry colds is again equalised in summer heats, for then the warm expanded water mounts to the surface, and keeps the lower stream in a healthful state, suitable to the finny denizens. Thus, as man penetrates into the workings of nature, does he ever have proof of a Wisdom controlling the machinery of the world, applied with an affectionate regard for the animated inhabitants that calls forth his gratitude and adoration.

PNEUMATICS.

THE magicians who have kept alive the wonder of mankind are the modern operative chemists : their magic has been science—their aim, truth. Like all great minds bent upon a noble object, they discarded crude and antiquated notions ; they cleared the ground of the weeds of ignorance ; and, starting afresh, have thought, tested, and proved their conclusions—simple from their truth, beautiful from their nature. They have exploded the old dogma, instilled into youth as learning, that there were four primary elements—earth, air, fire, and water. These modern philosophers have dissected and dissolved the same primary elements into many parts, and again re-united them into their previous condition. They have shewn that the accidental state in which the atoms may be found, can, by the appliances of man, be changed from the gaseous to the fluid, from the fluid to the solid state ; and that these are operations ever at work in the great laboratory of nature. That in comparison with the mass of the earth, the fluid that lies in the cavities, and covers such a vast extent of the surface, "comes to be conceived as a mere film of liquid, such as on a globe sixteen inches diameter would be left by a brush dipped in colour, and drawn over those parts intended to represent the sea ; while," continues Sir John Herschell, "we are led to regard the atmosphere of air, with the

clouds it supports, as constituting a coating of equable, or nearly equable thickness, enveloping our globe on all sides, or rather as an aërial ocean, of which the surface of the sea and land constitutes the bed, . . . and which is not more in proportion to the globe than the downy skin of the peach in comparison with the fruit within it."

The business of this portion of our work is to treat of the mechanical properties of elastic or aëriform fluids, as to their weight, density, compressibility, and elasticity—the word pneumatics being derived from the Greek word *pneuma*, breath or air.

Air is so light and thin, that when at rest it cannot be felt; and so transparent, that it cannot be seen. That air is a substance may be heard when a switch is passed rapidly through it, or a storm howls. It is felt in moving a fan; its effects are seen in the currents blowing about dust or leaves, and the hurricane prostrating trees—in the whirling of the windmill, and filling the sails of the stately vessel—in the rapidly-ascending smoke, which rushes aloft like a light stick from the bottom to the surface of the water—in the soaring eagle, beating it in his aerial flight, and in the balloon, ascending above the clouds, and being driven along by its currents.

THE ATMOSPHERE

is that aërial fluid, together with its clouds and vapours, in which man, animals, and vegetables exist. Man breathes it about twenty times every minute, or 1200 times in an hour; in quantity, about 18 pints a minute, or 1067 per hour, or 57 hogsheads 1 gallon 7 pints in a day. Without it in a pure state, man dies; for it keeps the machinery of his system in action, gives the vital principle to his blood, and warmth to his body. This applies also to the animal creation; for were there no air, their existence must cease. The vegetable kingdom spreads forth its delicate, porous, and arterial leaves, to breathe that portion of air rejected by man, and gives out, in the wonderful economy of nature, that portion beneficial to animal life. Thus is there incessantly going on a change advantageous to the peculiar conditions of vital creation.

If any thing that will hold a cubic foot of air be emptied by means of an air-pump, the vessel will then be found to weigh 523 grains less than when filled with air; should the same vessel be filled with water, it then will weigh nearly 1000 ounces less. Thus, then, as 523 grains are little more than an ounce, a cubic foot of water weighs about 840 times more than a cubic foot of air. In specific gravity, 1000 parts of water are taken in weighing solid and liquid substances; and in weighing air or gas, 1000 parts of common atmospheric air are taken as the standard.

One thousand parts of atmospheric air, on an average, consist of,

Nitrogen . .	788 parts	Aqueous vapour . .	14 parts
Oxygen . .	197 ,,	Carbonic acid . .	1 ,,

Then, by separating the gases constituting the air and weighing them, assuming their combined state which we breathe to be 1000,

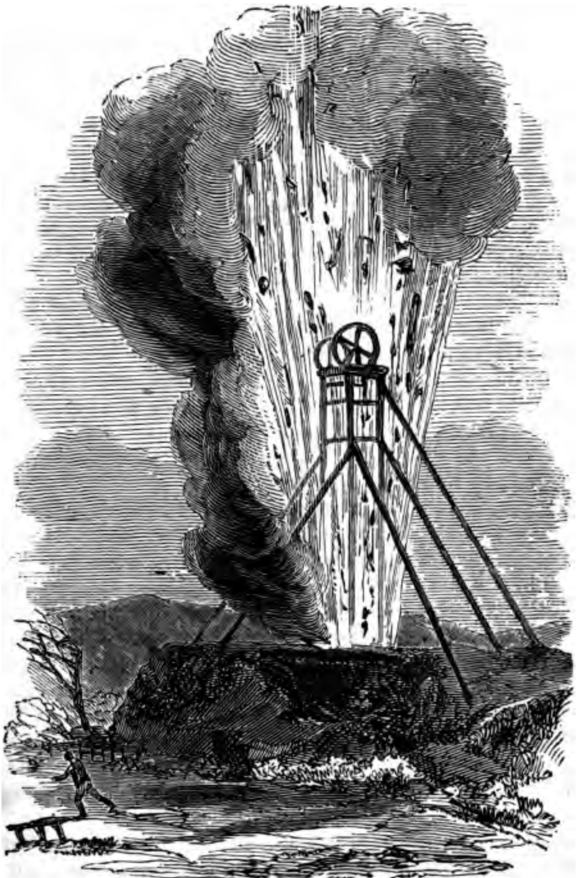
Nitrogen gas weighs .	972	Hydrogen gas weighs .	69
Oxygen gas ,, .	1111	Carbonic acid gas ,, . .	1529

Atmospheric air is not considered as a chemical compound, but as a mixture from the carbonic acid and aqueous vapour, being merely acci-

dental, not constituent parts, occurring in different quantities at different times.

Among the fifty-five elementary substances now known, the above four gases, in various combinations, act a most important part, which will excuse our digressing by naming some of the substances constituted by them.

Oxygen combined with *hydrogen* forms water; if an electric current be passed through water, the fluid becomes gas, and the hydrogen and oxygen may be collected in separate utensils. The gases may then be mixed, a spark of electricity sent among it, a loud report ensues, and they have again become water. The proportion is about 8 to 1 of hydrogen. When oxygen is abstracted from atmospheric air, animal life ceases; for



Fire-damp Explosion issuing from the mouth of a Coal-mine.

without it vegetation cannot exist, nor will fire burn; it is found in the ocean, the air, and in most solid substances. Oxygen and nitrogen, in various proportions, form atmospheric air, laughing gas, and aquafortis; with sulphur it forms sulphuric acid or oil of vitriol; with carbon, carbonic and oxalic acid; with lead, it forms red-lead; with metals, it forms their ores, called oxides—that is, they lose their former properties, and become a dry, earthy-looking powder.

Hydrogen is the lightest of the gases: combined with nitrogen it forms ammonia; with carbon, street gas and the air that issues from the fissures in the coal as the miner rends it from its deep-seated bed, which, accumulating and being ignited, is the cause of many lamentable accidents. See fig. 58. It forms one-ninth of the ocean.

Nitrogen forms with carbon cyanogen gas; it constitutes about three-fourths of the atmosphere, and one-fourth of animal flesh.

Carbonic acid is more than one-half as heavy as atmospheric air, and may be poured from one vessel to another. To breathe it is instant death; it is procured from burning charcoal. It collects in brewers' vats, and has been the cause of many fatal accidents. It makes soda-water, ale, &c. sparkling and brisk.

Hydrogen, nitrogen, and carbon form prussic acid. Oxygen, hydrogen, and carbon form alcohol, starch, sugar, and many vegetable productions. Oxygen, nitrogen, hydrogen constitute albumen, fibrin, gelatine, gluten, &c. of which animals are formed—the different properties being according to the proportions of these bases.

The elasticity of air may be seen by pressing a bladder which is filled with it; the bladder thus pressed will give way under the weight, but upon being relieved it will immediately resume its former bulk.

If the piston of a common syringe be forced down when the pipe is stopped, the air will be compressed; on removing the pressure, the piston is forced back again. Air can thus be compressed into about 100th of its usual space. If the pipe be still stopped, and the piston drawn up, then the air expands by becoming less dense.

The air lies, as it were, in strata, from the earth upwards, the lowest stratum being the most dense; as in a pile of wool, that nearest the ground is more pressed than that above it, and gradually becomes less and less compressed as it nears the top. A curious philosophical fact results from this density of the atmosphere, which is, in causing the rays of light to be bent as they approach the earth: thus they are more and more bent as the atmosphere becomes more and more dense. From this circumstance calculations have been made that the atmosphere does not extend further than forty or fifty miles above the surface of the earth; but its exact distance is unknown. That air must expand greatly, and consequently extend far, may be readily conceived, as, by experiment, it is found to possess considerable elasticity when only a thousandth part of its former bulk is left to occupy a certain space.

Air, like other fluids, is most dense at the lowest stratum, which is the level of the sea, as water is more dense the lower we descend in it. At the height of three miles, that is the summit of Mont Blanc, the air is found to be only one-half as dense as at the level of the sea; hence when a human being arrives there, although his chest is fully expanded, yet the quantity of air being only one-half that which he has been accustomed to

breathe, he feels great pain, and frequently falls down insensible. At six miles elevation the air is only one-fourth the density of common air on the earth's surface, and at nine miles only one-eighth. All the "blue etherial sky" of the poet is found to be of that delicate tint from the rays of light penetrating the atmosphere, and the clearer it is from clouds and vapour the more intense and beautiful is the colour. When Gay Lussac ascended in a balloon to the great height of 21,000 feet, nearly four miles, he found as he rose the blue gradually lessen, and a solemn, awful, black vault gradually presenting itself. The atmosphere possesses the power of holding in it clouds and vapours, which, like milk or mud in pure water, float about and are moved by the various currents. These present themselves as mist, rain, dew, snow, and hail. When the temperature of the atmosphere is high, moisture is absorbed; when lowered, it falls in the form of dew, rain, or snow. Philosophers have ascertained that the powers of the atmosphere could never hold more vapour than would cause six or seven inches of rain to fall at one time.

EQUAL PRESSURE.

Air or gas, like other fluids, presses equally in all directions, as may be felt in pressing upon a bladder of air, or filling an hydrostatic bellows with it instead of water. When the gasometer of a town is allowed to have additional pressure upon it, the lights in all directions suddenly start into a large flame, shewing that the pressure is equal in all parts.

PRESSURE AS TO DEPTH.

If a drinking-glass were covered by some such substance as a piece of bladder or thin India-rubber, and the air drawn out, a spring placed underneath would shew that the weight pressing upon the covering was equal to 15 lbs. on every square inch, therefore such is the weight of the air. If the covering were not supported, it would burst inward with a loud noise. The same experiment tried on the top of a high building would shew that the pressure was not so great there as on the ground, and as a greater elevation is attained, the pressure gradually lessens. Thus, then, a column of atmospheric air an inch square pressing on the surface of the earth is found to weigh 15 lbs., while a cubic foot of it is in density or weight a little more than an ounce. A cubic inch of air one mile high weighs a trifle over 43 ounces; and the weight of 15 lbs. gives a column of air a little more than 5 miles in height. In drawing up the air-tight piston of a closed syringe, by which the air is made to fill a larger space, it requires a force of 15 lbs. to every square inch of surface of the piston, this force being necessary to overcome the resistance offered by the pressure of the atmosphere outside.

PRESSURE OF AIR.

The air, then, presses with a weight of 15 lbs. on each inch of surface on every thing upon the earth; and as the average surface of a man's body is estimated at about 2000 square inches, he bears a weight of upwards of 30,000 lbs., or about 13 tons. This weight would crush the human frame and prevent man moving about, were it not for the law that

the pressure of air is equal in all directions ; the force of the outside pressure is equalised by the air contained within the body, and filling up all space in the bones, muscles, and other parts. This pressure in all directions keeps things in their places; for were it possible to empty a room of all the air it contained, the great pressure of the air would most likely cause the walls and the roof to fall inwards.

THE MAGDEBURG HEMISPHERES.

In 1654, Otto von Guericke, burgomaster of Magdeburg, first publicly illustrated the pressure of air on solids. He made two close-fitting cups or hemispheres *a*, *b*, one foot in diameter, which he filled with water; then unscrewing the handle *d* off one of them, which communicated to the interior by a hole, having a stop-cock *c*, he pumped the water out; after which he screwed the handle on again. This he presented at a public exhibition, when the emperor had six of his carriage-horses attached (by chains or ropes, as *e e*) to the hemispheres, but their strength could not pull them asunder. The resistance of the air was 15 lbs. on each square inch; yet when the stop-cock was turned and the air admitted, their separation was simple and easy.

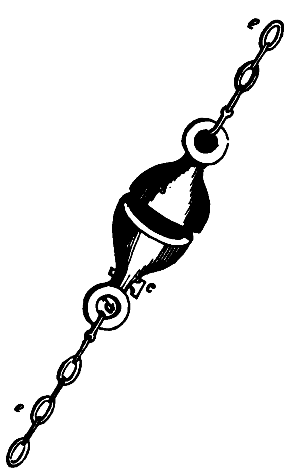


fig. 59.

Boys are in the habit of amusing themselves by procuring a round piece of leather, such as is used for the soles of shoes or boots, and steeping it in water, then making a hole through the centre they fasten in a piece of cord by knotting it on the underside: this wet *sucker* or *cleaver* they press upon a stone, and, pulling the cord, if the stone be loose and not too heavy, they by this means can lift and carry it about. The leather must be of such a grain as not to admit air underneath, and thick enough not to bend too much. There being no air below, the leather is kept in its place with a force equal to 15 lbs. on each square inch of the surface of the sucker, and will lift a stone in accordance with this power.


fig. 60.

On this principle, that of shutting out the air from one part and having its pressure on another, arises the power of flies, and some other insects, to walk on ceilings and the upright glass of windows. Fig. 61 is a greatly magnified view of the sucker attached to the under surface of the house-fly's foot. The construction of their feet allows of a ready formation of suckers, and power at will of admitting the air to relieve them: it

is estimated that a fly, when walking, in the course of a minute performs this operation 10,000 times. The fishes called by the poor living at the sea-shore "clockers," adhere to rocks by a sucker on the underpart of their bodies, and when the tide has receded send forth a sound causing the uninitiated to search for a hen desirous of setting eggs, instead of which they discover a fish clinging to the rocks. Snails, periwinkles, limpets, &c., possess this property.

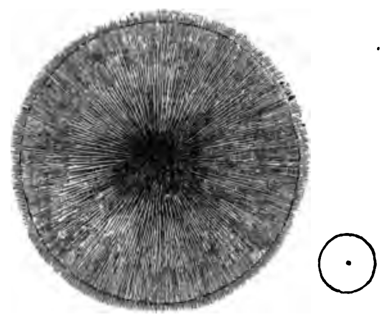


fig. 61.

The small black spot is intended to shew the natural size of the fly's foot.

SYRINGES.

There are two descriptions of these philosophical instruments: one for forcing more air into a vessel, called a *condensing syringe;* and another for drawing air out of a vessel, which is named an *exhausting syringe.* Both consist of a tube closed at one end, excepting an orifice to which a valve is affixed. In the condensing syringe this valve opens downward; in the exhausting syringe the valve opens upward. A piston with a handle and rod is put in at the other end of the tube, and can be moved up and down; each of these pistons has valves opening in the same direction as the valves of the tubes. If the exhausting syringe be affixed to a vessel, the piston being down, on drawing it up, the valve in the piston is kept shut by the pressure of the external air, while the air in the vessel, pressing on the valve at the bottom of the tube at the rate of 15 lbs. on the square inch, raises it, and the air in the vessel passes between the valve in the piston and that in the bottom of the tube. When the piston is pressed down, the valve at the bottom closes and that in the piston opens, and thus the operation is continued until the vessel be pumped free from air.

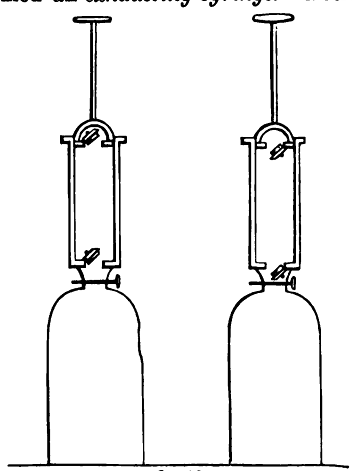


fig. 62.

In the condensing syringe the valves are hung so as to act in a contrary direction: when the piston is pushed down, the pressure of the air in the tube and vessel shuts the valve in the piston, and the air in the tube is forced into the vessel; on drawing up the piston, the pressure of the air within the vessel closes the valve at the bottom of the tube, while the external air opens that of the piston; on shoving the piston down again, the piston-valve closes, and the air in the tube forces the tube-valve

open and the air into the vessel. Thus the operation is continued as long as the party has strength to force more air in, or the vessel to bear it.

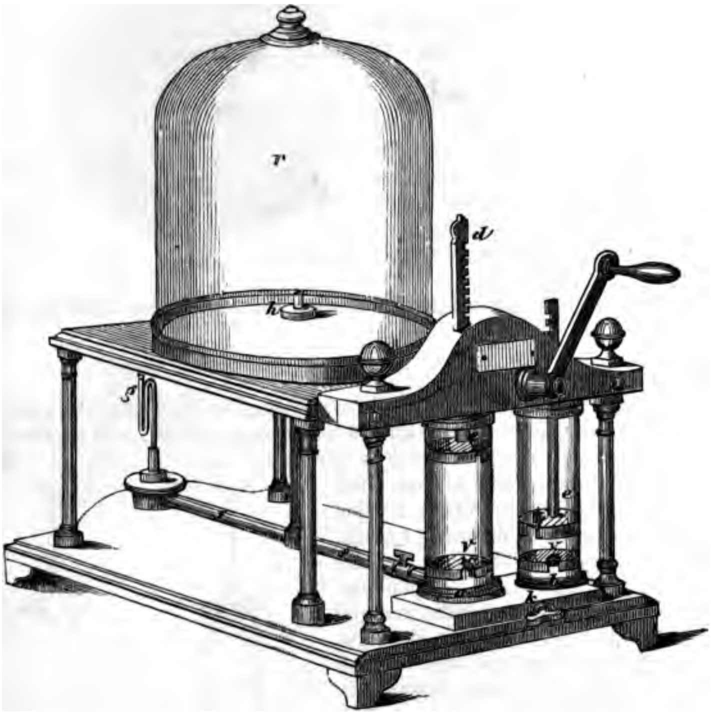


fig. 63.

THE AIR-PUMP.

This instrument is for the purpose of withdrawing the air from any closed vessel. Thus it may be drawn from a bag or bladder; but for general experiments there is a round glass with an arched top *r*, open at the bottom, called a receiver. This glass is placed with its open part downwards on a flat smooth surface, usually a metal plate, and where it touches the plate there is a piece of wet leather to render it perfectly air-tight. In the metal plate is a hole *h*, communicating by a tube *ff* with two strong brass pump-barrels *a*, *b*. In each barrel is a valve *v v*, opening upwards, and also valves *e e* in two tightly-fitting pistons: at the top of these pistons is some rack-work *d*, which works in a little cog-wheel attached to a handle. A half-circular turn being given to the handle, the pinion works the racks up and down. On each of the pistons rising, the air rushes from the receiver into the vacuum created in the barrel. As the pistons alternately descend, the air escapes from the barrels, and thus the handle is worked until all the air under the receiver is drawn away. The purpose of having double barrels is to expedite the operation.

In the cylinder or barrel *a* the piston is represented in the act of ascending when the valve *e* is closed, and a vacuum would be formed

beneath the piston but for the opening of the valve *v* by the elasticity of the air in the receiver *r*. In the barrel *b* the piston is in the act of descending when the valve *v* is closed and the valve *e* open, by which all the air in the cylinder is forced out; and in this manner a portion of the air is withdrawn from the receiver *r* at every stroke of the pump. *k* is a cock, by turning which air is re-admitted into the receiver and thereby loosened; *g* is a small tube filled with mercury, which, from the mercury sinking as the air is exhausted, shews the extent to which it is effected.

In the working of this useful philosophical instrument, the utility and effect of the simple contrivance of a valve must be very striking. As the air rushes out, it gives way and allows it to pass; but as soon as it attempts to enter, it closes, and the more forcibly it pushes, the closer and tighter does it become.

Many useful experiments are made with the air-pump. The weight of the air may be personally felt by placing the hand on one end of a glass tube which is open at both ends, and the other end being placed over the hole of an air-pump; on exhausting the air, the weight of the external air is felt most painfully. If the hand be removed, and a piece of parchment substituted and tightly tied on, it will sink inwards and finally burst with a loud report.

A glass of liquid placed underneath a receiver, on the air being withdrawn will bubble up, from the air contained in it escaping; and by this means is seen the amount of air held in many liquids and solids.

A favourite experiment is to place a shrivelled apple under the receiver, when it assumes all the plumpness and smoothness of fresh ripeness instead of the wrinkles of age; but when again presented to fresh air, the apparent youthfulness is lost, and the appearance consequent on its natural condition returns.

A bladder half filled with air and tightly tied at the neck, when similarly treated will expand till it bursts. An egg with a prick in the narrow end, if under an exhausted receiver will become empty, from the air contained in the broad end expanding so as to force out all the delicate food encased in the shell.

These facts illustrate *the expansion of air*. The rarety of air must be very great, for if only one-thousandth part of the quantity contained in the receiver be left, there will be spring enough to move the valve of the pump.

As the valves in certain constructions of air-pumps are apt to get out of repair, it is a desideratum to have an apparatus without them. Mr. Ritchie has invented one to act without valves, and it is therefore proportionally simplified in construction. The diagram is merely illustrative of its action, not of the arrangement of the parts, which may be made to suit convenience. A barrel, *a a*, is provided with a piston, the rod of which works through an air-tight stuffing-box at *g*; the receiver *d* standing on a table *f* is connected to the barrel by a pipe *ee*. There is a small hole in the cover at *c*, similar to the vent of a flute. Suppose the piston at the bottom of the barrel beneath the aperture of the pipe *e e*, it is then raised, the air above it being forced through the aperture *c*; the finger is then put on *c*, by which it is closed perfectly air-tight; the piston is pressed down, and forms a vacuum above it: immediately on the piston

passing the aperture of the pipe *e e*, air from the receiver rushes into the barrel to fill up the vacuum. The piston is then raised, and the air passes through *c*, the operation being repeated till the requisite degree of extension is obtained in the receiver *d*.

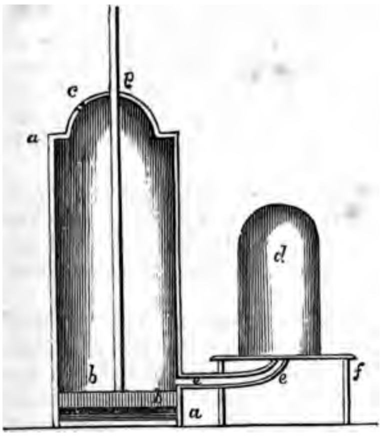


fig. 64.

The principle of the air-pump has been long applied to manufacturing purposes. Watt adopted it in his steam-engine; and in paper-making, sugar-making, and tanning of leather, and numerous other purposes, it has been successfully used. A machine is fitted up similar to an air-pump, having a tube connected with the syringe and a receiver; but in this case the receiver is firmly fastened down by a cross-piece of some material affixed to pillars. By reversing the valves of the air-pump, a condensing syringe is easily made.

Some use has been made of this condensation of air, as it has been substituted for the moving power of bullets in what are called *air-guns*, instead of the gases created by firing gunpowder. In those guns, a condensing syringe fills a cavity having a valve opening inwards, just behind the bullet, which fits the barrel exactly. The air being condensed about forty times that of the atmosphere, possesses a force of about forty times 15 lb. on the inch, and, upon the trigger being touched, a valve is opened, which, allowing the air to rush out, propels the bullet with this force. The air closes the valve the instant the finger is withdrawn from the trigger. Each discharge is weaker than the one preceding, from the air becoming less dense. Some of these guns have reservoirs of bullets, so that a continuous firing may be maintained as long as the condensed air lasts. The *air-cane* is merely the barrel of the gun with the air previously inserted by means of a condensing syringe.

Science has now entered so intimately into our every-day concerns, that the current literature teeming from the press is continually using terms familiar to those practically engaged; therefore it may be as well, more especially as such belong to the present subject, to explain what is meant when we speak of the power of the *atmosphere*. We have already stated that the pressure of the air is equal at the earth's surface to about 15 lb. on every square inch, while it has a density or weight equal to 1 ounce troy for each square foot at its lowest stratum. Now, this weight of 15 lb. on the square inch is called the pressure of *one atmosphere*. If 15 lb. to the square inch be added to compress air, it then fills one half its former space, and its density is called a *double atmosphere*. With twice 15 lb. then it is of triple density, and said to be *three atmospheres*. In this manner a steam-engine or air-gun is spoken of as possessing a resisting medium of so many atmospheres. If we ascend into the heavens, or expand air by artificial means until it possesses only one-half of the density

at the earth's surface, then it is spoken of as only *half an atmosphere*, and so on.

From a knowledge of the powers of compressed air many useful articles for domestic uses are formed, as table-lamps, shower-baths, and others, while a little refreshing parlour fountain adds to the charm of an adjoining conservatory. The last-named elegant jet is construed in every variety of design, but the principle of action is the same in all. It consists of a vessel *a a* partly filled with water, either air is then compressed into the vessel, or by means of an air-pump air is extracted, and upon turning a cock the water spouts up through a pipe *b* inserted in the vessel and reaching near to the bottom. A little stout cherub struggling with a dolphin is a favourite device, the water issuing from the mouth of the captured fish.

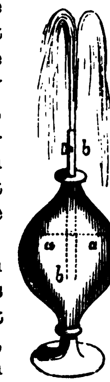


fig. 65.

The application of condensed air is of infinite service in many water-works having to supply large towns; for as filling the pipes direct by the working of pumps would cause it to flow in gushes, the water is pumped into a covered receiver, by which the air in it becomes condensed, and pressing on the surface, makes the supply uniform, and gives the necessary pressure to keep the pipes constantly charged.

Thus, suppose *a a* to be the pipe through which the water is forced; it passes through the valve *e*, opening inwards to the vessel *b b;* the air accumulating in the upper part of the vessel at *c c*, presses upon the surface of the water, which sends it up the pipe *d d* in a continuous stream.

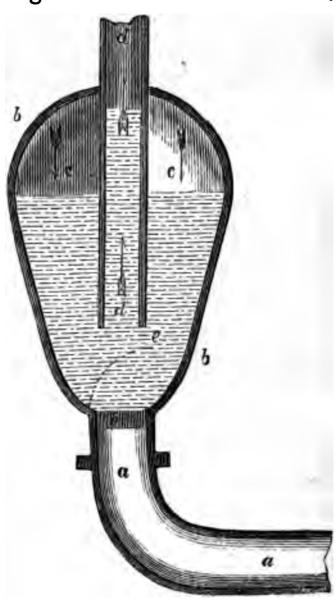


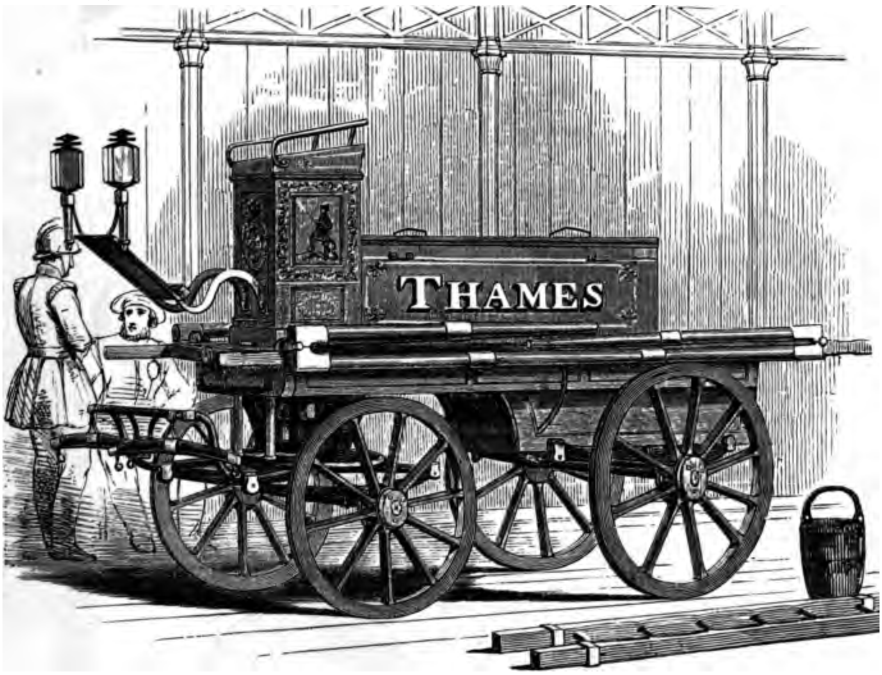
fig. 66.

It may be remarked, that here the water is pressed into the receiver by means of what is termed a forcing pump, the power of which compresses the air. If the air be by this means condensed to a double atmosphere, the pressure would raise water 33 feet, if to a triple atmosphere 66 feet, and so it will increase in power to raise 33 feet for every additional atmospheric pressure applied.

On this principle are those valuable engines used in the appalling calamity of fire, that appear in the hour of despair like so many angels of hope and faith to the agonised. The continuous stream pelts the contending element not only with its liquid nature, but with force penetrates its fiery foundation.

Fire-engines were used by the ancients, and introduced into England about the year 1700. They may be described as consisting of an oblong wooden chest, or cistern, along the lower part of which runs a metallic pipe, into which the water flows from a feed-pipe connected at the other

end with a street-plug or reservoir of water. The water having entered, the interior pipe is elevated and forced into an upright air-vessel by two



Fire Engine.

pumps, which are worked by men by means of long handles placed at the outside. From the air-vessel the water is forced into a pipe connected with the leather hose, and then directed against the burning edifice. If well constructed they will throw a stream of water 130 feet in height; but it will be well to remember what we stated on the flowing of water through pipes, page 78, that an elevation of an angle of 45 degrees will throw water the greatest distance, which also applies to the engines we are now describing.

The following figure illustrates the action of the fire-engine. Two pump-barrels *bb* are placed in the cistern *aa*, and surrounded with water to the level of *á á*. Each barrel has a piston *b b*, attached by rods *i i* to an oscillating beam *g g* working in the centre, moved by the handles *h h*. The valves *cc* open inwards to the barrels, and those marked *dd* to the receiver *ee*. By the working of the barrels a continuous stream is projected through the pipe *k* in the centre of the receiver to which the hose is attached. It will be seen that the water, being pressed by the pistons into the receiver *e*, is resisted by the air at the top of the receiver, and thus seeking an outlet rushes with impetuosity through the pipe *k*, and is directed to the proper object by the hose being screwed on at *f*. The little portable and useful engines used in gentlemen's gardens are on a similar principle.

Observing that on thrusting a glass with its mouth downwards in water,

the air resisted the liquid so as only to allow it to rise a little height in the glass, gave rise to that valuable modern invention the *Diving Bell.* By means of this invention much treasure has been rescued from the bottom of

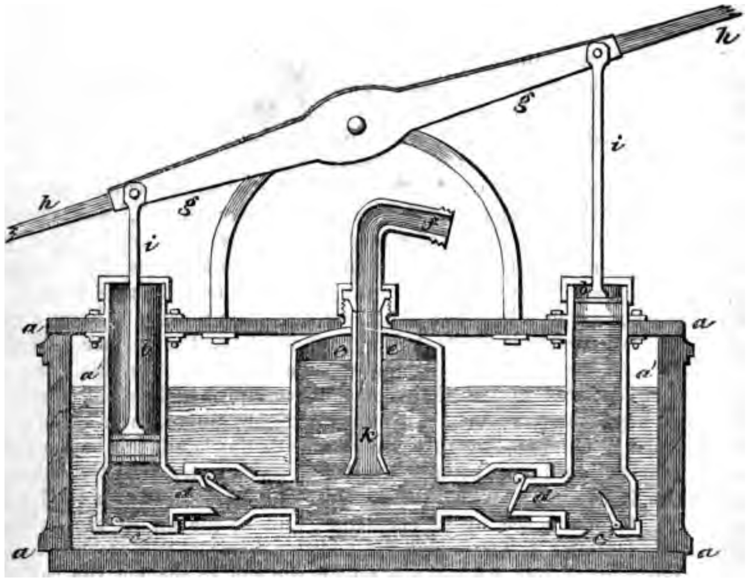


fig. 63.

the ocean, the foundations of lighthouses have been laid, the walls of piers constructed under water, and the foundations of bridges built and repaired. These bells are sometimes square, and sometimes in the form denoted by their name. They are either made of heavy material, or have appliances to cause them to sink. When lowered from the attendant ship or barge laden with workmen, the air becomes compressed, and if sunk to a depth of 34 feet, the air in it is compressed to one-half, or to a double atmosphere. This would allow of the vessel being half-filled with water, while the air would be so condensed that the men would inhale at each breath twice as much as they were accustomed to do on land; therefore, not only to ease the pressure, which is according to the depth the bell is in the water, but also to give vitality to the air, a pipe is connected with it, through which fresh air is forced down to the men by means of a pump; while at the top of the bell is a cock by which the air that has been breathed is allowed to escape. When it is necessary to leave the bell to travel a short distance, the man having to do so puts on a helmet, and has a pipe leading to it from the bell: should the ground in his exploring expedition be so uneven that he either rises above or below the level of the air in the bell, he at once feels it; when above, the air rushes to him, and becomes so compressed that he with difficulty breathes; and if below, the sluggish supply renders exertion necessary. Still, such is the excellence of arrangement for prosecuting submarine labour, that since the novelty has worn off, it is undertaken without more than the ordinary danger attendant on manual operations, and adopted as a common branch of industry. On

first going down, a painful sensation is experienced in the ears, which a cunning fellow thought he could avoid by placing in his ears some chewed paper; the consequence was, the pressure of the air forced this material inwards, and it required some surgical skill to save the life of the would-be-clever but unphilosophical man.

The situation of the diving-bell at the depth of 34 feet presents this difficulty to be overcome—the water presses on the air in it with a force of 15 lb. per inch; the power of the forcing-pump to overcome this resistance, by which the under-sea toiler may pursue his avocations with bearable comfort, must be extraordinary.

The truths of science were often demonstrated to the vulgar as mere toys, to excite the wonder of "children of a larger growth," and delight the eager and inquiring spirit of rising generations. Amongst those, we know of none more appropriate to our present theme than the little balloon floating in a glass jar nearly filled with water. The balloon is formed of glass, hollow, having a hole at the narrow end, from whence is hung a car. By placing it in water it floats, half appearing above the surface. Water is poured into the balloon until the specific gravity of the little toy is nearly that of water, and it then floats in its liquid bath about midway. The jar is next closely covered with a piece of parchment, india-rubber, or gutta percha. On pressing this covering with the hand, the balloon descends; for the air being compressed, forces more water into the balloon, and causes it to sink. When the pressure is taken off, the air in the jar regains its former space by its elasticity; and as the air in the balloon follows this law also, it forces out the additional water, and ascends to its former position. Thus, with the hand on the top of the jar, the balloon may be made to rise or fall at the word of command, without, to the uninitiated, any apparent power to influence it. Should the balloon, however, in the experiment be forced down until it reaches the bottom of the jar, it remains there from the superincumbent weight of water overcoming the elastic power of the air contained in it; but by tilting the jar on one side, and thus lessening the weight of water, its first position is recovered.

This toy exemplifies the elasticity of air; as on the pressure being removed, the air resumes its previous space; also that air is a substance, and capable of compression; and as the balloon floats from having air in it, that it is light; it illustrates fluid support, pressure in all directions, and pressure as to depth; for the lower the little machine sinks, the lighter is the pressure required on the covering of the jar.

This beautiful experiment is diversified and rendered more strange and diverting by having little glass men instead of a balloon, with a small hole in the feet; these are adjusted to take different positions in the jar, and on pressure the lowest first descends, then the one above him, and so on; on lessening the pressure, the lightest returns first, the others following. When scientific discoveries were exhibited for sport more than instruction, the jar with those figures was turned with the mouth downwards, and a hole being made in the table, having a contrivance by which the "conjurer" with his foot could press on the elastic covering, he delighted his audience by ordering the little figures to move downwards, to stop, or to ascend at the word of command; which always provoked hearty applause.

Amongst other contrivances for adding to the gratification of polished

and elevated society, is the beautiful little fountain or *jet d'eau* of Hiero, which illustrates the elasticity of air. The annexed figure will explain the *rationale* of the operation of this elegant toy. A vessel or air-tight box *a a* is supplied with water from the box *b*; a pipe *c c* leads from the top of *a a* to near the top of another box *f f*, made air-tight. The water descending from *b* forces the air up *c c*, and acting on the surface of the water in *f f*, forces it out by the pipe *e e*.

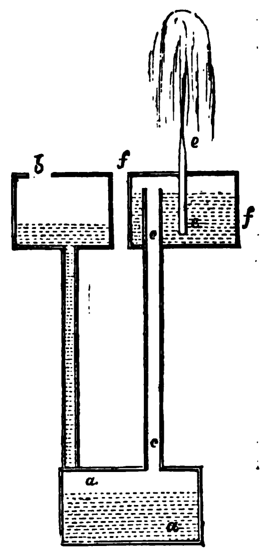


fig. 69.

Fig. 70 shews one of the many devices for making this philosophic toy ornamental. The water is placed in a vessel A, in a hollow stand B, and a small pipe C proceeds from the vessel of water up a hollow tube D. Water is then poured into the ornamental basin E, upon which it forces its way down the tube D, and pressing upon the air in B, the water in A rushes up the pipe C, and forms a beautiful jet of water. As the pressure is produced by the water in D, whatever length that tube is, such will be the height of the jet. Upon the water becoming exhausted from A, that which has fallen from E to B is removed, and A and E being replenished as at first, the action of the fountain is again commenced.

Another instance of the pressure of air is that common experiment which is performed to amuse and astonish children by filling a wine-glass full of water, then covering it with a piece of paper, and turning its mouth downward, the water remaining in the glass, from the pressure of the air against the paper. There is also a familiar instance in the glass reservoirs of bird-cages, where the water remains a considerable height above the part from which the little feathered prisoner drinks; the pressure of the air on this part sustains the water in the fountain.

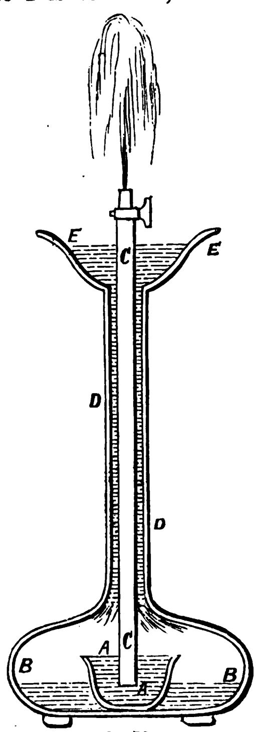


fig. 70.

THE COMMON PUMP.

If we take a straw, and place one end in water and the other in our mouth, then draw in the breath, we create a vacuum; the air in the straw first rushes into the mouth, and is followed by the water; this arises from the pressure of the air on the water forcing it into the part where a vacuum has been produced.

On this principle the useful and common contrivance called the sucking-pump is constructed. It consists of a hollow tube, having a close piston A, with a valve opening upwards, made generally of a piece of lead fixed to leather, and at-

tached by a hinge. B is a hollow tight-fitting plug with a valve, the same as the other, but placed in a lower part of the tube. On pressing the handle C down, a vacuum is created between A and B; and the air pressing on the water, it rushes up the tube E, raises the valve B, which closes from its own weight, and that of the water above it. On A descending, by the handle C being raised, the water between A and B forces up the valve A, which closing on the handle being pushed down, lifts the water up to the spout F, where it flows out. In doing this, a vacuum is again created between A and B, followed by more water; and thus the operation is continued as long as required.

Now, suppose a tube closed at one end was filled with water, and then the open end placed in a vessel of water, the fluid would remain in the tube at the height of 34 feet; this shews that the weight of the atmosphere on the earth is equal to a column of water 34 feet in height, or that of 34 feet of water surrounding the whole globe. From this fact in nature, a pump cannot be made to draw water from a greater depth; therefore when such a circumstance occurs as to render the operation necessary in a very deep mine, a succession of pumps is employed,

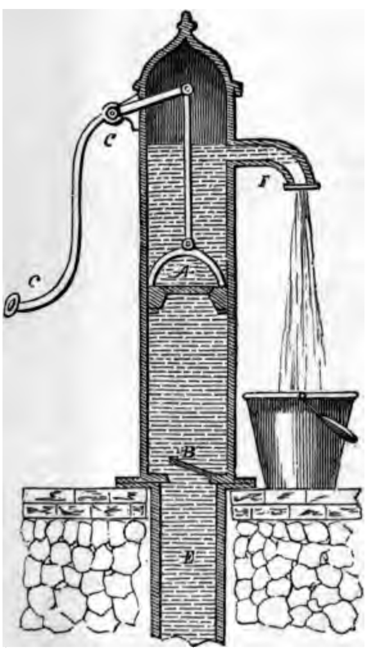


fig. 71. Common pump.

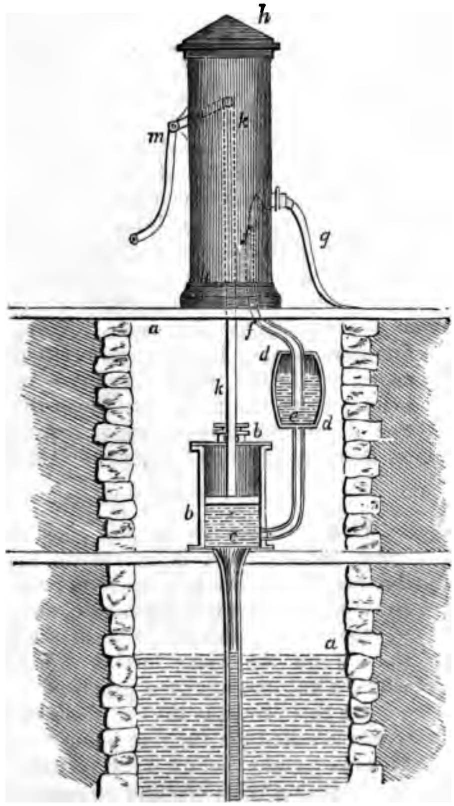


fig. 72. Forcing-pump.

averaging about 28 feet draught each; or another arrangement is employed termed the

FORCING-PUMP.

The reader, by referring to page 97, in which we gave a drawing of the arrangements of a fire-engine, will at once perceive the action of a force-pump. We now give another sketch, shewing its application to a useful purpose, and an inspection of which will make its operation easily understood. A well *a* in a street is provided with a pump-barrel *b b* in which works a tight-fitting piston, a valve opening upwards is placed at the bottom of the barrel at *c* and another at *e*, in the inside of the receiver, an air-vessel, *d d*. In the centre of the street, above the well, an ornamental pedestal *h h* is placed. In the centre of this the piston-rod *k k* of the barrel works, being operated upon by the handle *m*. A pipe *f f* proceeds from the air-vessel *d d*, and is terminated by a screw junction, to which the hose *g* is attached when required. The whole apparatus is designed for a permanent force-pump, to be used in the extinguishing of accidental fires occurring in the street in which the apparatus is placed. Its operation is as follows:—On the handle *m* being depressed the piston is raised, creating a vacuum in the lower part of the barrel and causing the water to fill it, passing through the valve *c*. On the handle *m* being raised the piston is depressed. The valve *c* closing tightly prevents all egress through it: the water therefore is forced up the pipe leading to the air-vessel through the valve *e*. It is by the pressure of the air in the air-vessel forced up through *f* and out at the orifice of the hose *g* in a continuous stream or jet. As the chamber *d d* contains air it becomes compressed by the water, and according to the force of its condensation does the water fly out of the pipe *f* and hose *g*. Thus, if the air be compressed one-half, it will press on the water with the force of a double atmosphere, and be sent the height of 33 feet; and if to one-third its former space, the water will spout in a uniform stream to the top of a building 66 feet high, and so on, according to the pressure on the air by the water.

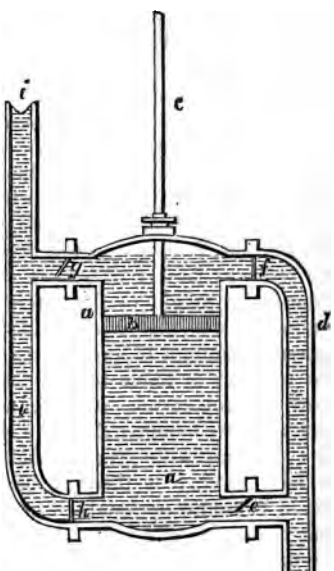


fig. 73.

The great defect of forcing-pumps where air-vessels are used is the absorption of the air by the issuing water, so that in process of time nearly all the air in the receiver is passed out by the water, consequently becoming intermittent. To obviate this defect, an arrangement in the following manner is made. The pump-barrel is at *a a*, the piston at *b*, and the piston-rod at *c*, *d d* is the pipe communicating with the water to be pumped up. On the piston being raised the valve *e* opens, and a vacuum being produced beneath the pis-

ton, the water rises from the well; while this part of the operation is being performed, the valve *g* opens, and the water above the piston-rod is lifted up and forced out at *g* into the delivery-pipe *i i*. On the piston-rod being depressed the valves *e* and *g* close, and a vacuum being created above it, the valve *f* opens and admits the water from *a* to that part of the barrel above the piston; at the same time the valve *h* opens, and as the piston descends the water beneath is forced through *h* into the delivery-pipe *i i*. It will thus be plain that there must be a continual stream of water forced through the delivery-pipe, as both the down and up stroke act in giving permanence to that effect.

The reason for using the principle of the force-pump to supply the boiler of a steam-engine with water is, that the pressure of the steam in the boiler may be overcome. Should, however, the pump be applied to raise water which has more than 150 degrees of heat, on the piston being lifted up the expected vacuum will be found filled with steam given off by the water, and the pump therefore labours fruitlessly.

By the application of a pneumatic principle a most important improvement has taken place in pile-driving for the foundations of bridges, piers, and other erections in water where the ground consists of mud, sand, earth, gravel, or clay. Instead of having large beams of timber driven in by the force of a weight dropped from a height, the piles are cast-iron cylinders: these are hollow and placed perpendicularly over the spot where they are required to be sunk; the top is made air-tight by fixing on it a cast-iron plate through which a tube is passed connected with a common air-pump. On working the pump a partial vacuum is created in the cast-iron tube, and the earth or other substance at the bottom consequently rises up, while the tube descends into the place thus made for it. Recently on building a bridge across the Shannon the pneumatic piles were the enormous size of ten feet diameter; had timber been employed the piles would have been one foot square. A vacuum inside the tubes equivalent to 13 lbs. on a square inch was created by the air-pump, and the descent of the ponderous tubes into a bed of yellow clay seemed a work of magic. Thus it is that science is ever aiding the industry, the comforts, and the safety of mankind.

An atmospheric pile-driving machine has been patented by Messrs. Clarke and Varley, and was used at Irongate-wharf, London, in sinking the ordinary timber piles. It is well known that in the common crab-engine the weight of the rammer is necessarily limited by the amount of manual power that can be conveniently brought to bear upon it; and the necessary amount of force in the blow is made up by the height from which the rammer is made to fall. But on the principle we stated under the head of momentum, it is found that a succession of short quick blows with a heavy hammer does the work, not only with much greater speed, but in every way with greater efficiency; also damaging the timber less, and, in fact, forcing it through hard ground which by ordinary methods it would be found impossible to penetrate. By this invention, it would seem that the power of a steam-engine fixed at any convenient spot can, through the medium of atmospheric pressure, be made available at any required distance by the simple application of a vacuum cylinder with its apparatus of self-acting valves, chains, and pulleys, and be attached to a pile-driving machine of the common construction.

The machine was worked by a small high-pressure steam-engine fixed on the shore, to which was attached an air-pump for producing exhaustion. Communication was made with the pile-machine by lengths of small galvanised iron pipes, connected together by flexible joints. Within this is a piston, connected by an iron rod to a chain which passes over a pulley on the top of the frame, the other end of the chain being fixed to a suspended pulley; over this passes a second chain, one end of which is attached to the rammer, and the other passes down to the bottom of the engine, whence again returning upwards it is fastened to the top of the pile. The action, then, was this: the rammer being down on the head of the pile, and the piston consequently at the top of the air-cylinder, the air in the cylinder was then rarefied by the action of the air-pump above, until the external pressure was sufficient to counterbalance the weight of the rammer; this then immediately rose, and as soon as the piston reached the bottom of the cylinder, a motion took place in the self-acting slides, by which the air was suddenly admitted under the piston; equilibrium between the pressures above and below being thus restored, the rammer immediately fell with its whole force on the pile, bringing in its progress the piston again to the top of the cylinder, when, the slides being reversed, the operation was repeated. Thus a constant succession of short heavy blows was given, and did not cease until the pile was driven to the required distance into the soil. And as, by the arrangement of pulleys, the distance between the pile-head and the rammer was always the same, a regularity of action was obtained, quite unknown in the old pile-driver.

The machine itself required no attendance while in operation; only one man was employed occasionally wedging up the pile to preserve its true direction. It was moved with great facility from pile to pile, being very little heavier than the common crab-engine. Under the cylinder was fixed a small crab, used to raise the pile to its place previously to being driven.

AIR-ENGINES.

The cost, the weight, and the bulk of coal necessary to generate steam, have led many ingenious persons to attempt the discovery of a new power to work machinery, and, as the cheapest and most universal material, they have tried to use air for that purpose. The force existing in that elastic fluid, when compressed or rarefied, is the power that many ingenious men have been straining their inventive faculties to enchain and make obedient to their will; this has been effected with partial, not complete success.

At an iron foundry in Dundee was erected an air-engine, patented by Mr. Sterling; it is thus described in Knight's *Industry of all Nations:* "In this engine two strong air-tight vessels are connected with the opposite ends of a cylinder, in which a piston works in the usual manner. About four-fifths of the interior space in these vessels is occupied by two similar air-vessels, or plungers, suspended to the opposite extremities of a beam, and capable of being alternately moved up and down to the extent of the remaining fifth. By the motion of these interior vessels the air to be operated upon is moved from one end of the exterior vessel to the other; and as one end is kept at a high temperature, and the other as cold as possible, when the air is brought to the hot end, it becomes heated,

and has its pressure increased; whereas its heat and pressure are diminished when it is forced to the cold end. Now as the interior vessels necessarily move in opposite directions, it follows that the pressure of the enclosed air in the one vessel is increased, while that of the other is diminished; a difference of pressure is thus produced upon the opposite sides of the piston, which is thereby made to move from one end of the cylinder to the other; and by continually reversing the motion of the suspended vessels or plungers, the greater pressure is successively thrown upon a different side, and a reciprocating motion of the piston kept up. The piston is connected with a fly-wheel, in any of the usual modes, so as to communicate motion to machinery. There is a furnace to heat one end of the air-vessels, and a water-pipe refrigerator to cool the other; and the air traverses numerous small channels in its course from the one end to the other, in such a mode as to economise the heat."

Ingenious contrivances have been made public, for propelling railway carriages and other machines by the explosion of gunpowder continuously in small quantities, and also by the flashing into vapour of liquid carbonic acid and ammoniacal gases; but the public seem not to delight in the idea of being sent to the end of their journeys by explosions and flashes, and hence the schemes have made no progress.

The smoke-jack connected to the spit, on which many a baron of beef was roasted when the houses of the wealthy were thrown open to the necessitous and the wayfarer, was turned by the force of the heated air ascending up the chimney, and acting upon a set of vanes like those of a windmill or ventilator; the power of the ascending column of air depending not on the amount of smoke, but on the strength of the fire.

At New York there is an extensive bakery where machinery is worked by a force equal, it is said, to several horse power, gained by a tall column of air. The heat arising from the bakery ovens rarefying the air, a partial vacuum is made which the dense outward air rushes in to fill up; this ascends up a tall straight chimney, in which there is fixed a wheel laid flat, having vanes at an angle of ten degrees. The wheel turning round communicates motion to certain machinery which grinds the corn and kneads the dough. We put this on record, but think some power of the imagination has aided the reported powers of the machinery.

A few years ago an atmospheric carriage ran on the turnpike road from Putney to Wandsworth at a speed of twelve miles an hour. The air reservoir measured seventy-five cubic feet, and by the aid of a steam-engine the air was compressed to a force of fifty atmospheres, or about 700 lbs. on a square inch. From its discontinuance, and the example not being followed, we may justly suppose it was unsuccessful; in fact, the principle is erroneous, as we shall have afterwards occasion to point out.

Some years ago Mr. Vallance proposed the forming of tunnels of sufficient dimensions to hold carriages; which being introduced at one end, the air was to be exhausted by a steam-engine at the other end, when the carriages would be shot along by the pressure of the atmosphere at the open end. The plan was considered ingenious but not of practical utility. It was, however, suggested that the plan could be adapted to the transmission of letters, newspapers, &c., but no steps were taken for carrying the suggestion into practice.

In 1834, Pinkus brought forward a plan for the carriages travelling

outside the tube instead of inside, and this led to what is now known as the atmospheric railway. An experiment at Wormwood Scrubs shewed that a load of six tons could be propelled at a rate of thirty miles an hour with a tube nine inches diameter. The extension line of the Dublin and Kingstown Railway to Dalkey, a distance of about a mile and three quarters, required to have extremely steep gradients, frequently as much as 1 in 50 feet, and sharp curves. The usual locomotives being inapplicable, the atmospheric principle was called into requisition, and with a vacuum of 26 inches a speed of 35 miles an hour was obtained. The carriages returned by their own gravity. The Croydon Railway, with a vacuum in the tube of 27 inches, obtained a speed of 60 miles an hour; on this railway a train of 10 carriages, weighing 50 tons, was propelled at a rate of 35 miles an hour. The diameter of the tube was 15 inches, the air-pump 6 feet 3 inches in diameter, the engines three miles apart, and a power of 300 horses employed for the whole distance. The steepest plane was 1 foot in 50. The principle of atmospheric propulsion, from the frequent derangement of the mechanism, has been abandoned on this line and locomotive engines adopted.

Pilbrow, in 1844, made several ingenious improvements in this system, but it has not gained approval from scientific men.

From the *Illustrated London News* we copy the following accurate description of the principle and working of the atmospheric railway:

"In the atmospheric railway, a pipe of about twelve inches diameter is laid between the rails on which the carriages run; this pipe is exhausted at one end by an air-pump; a travelling piston is forced along it by the pressure of the atmosphere; and a rod, or plate, of iron, connecting the piston with the carriages, traverses a slit on the top of the pipe. The great difficulty to be overcome was to cover this slit with a substance which would be air-tight, and yet would permit the connecting-rod to pass without offering much obstruction. The plan adopted by Messrs. Clegg and Samuda, the projectors of the system as improved, will be best understood by reference to the accompanying diagrams.

"Fig 74. represents a vertical section of the pipe. The opening at the top is covered by a continuous valve G, extending the whole length of the pipe. It is formed of leather riveted between two iron plates. The upper plate is wider than the slit, and prevents the leather from being pressed in by the pressure of the atmosphere; the lower plate just fits the slit, and is curved to the shape of the pipe. One edge of the leather is fastened to a longitudinal rib cast along the opening, and forms a hinge, as on a common pump-valve. The other edge of the valve, when it covers the opening, forms, with a ridge cast on the pipe, a channel or trough on its whole extent, a section of which is shewn at F, fig. 75. This trough is filled with a composition of bees-wax and tallow, which, when melted and cooled, adheres to the side of the valve and keeps it air-tight. As the travelling piston is forced along the pipe, one side of the valve is raised by four small wheels fixed behind the piston, so as to admit the connecting rod C to pass as in fig. 74. The opening thus made also admits the air to act against the piston. The rupture thus made in the composition of wax and composition of wax and tallow is cemented again, before the train passes, in the following manner:—A steel wheel R (fig. 75), regulated by a spring, is attached to the carriage, and presses down the valve imme-

diately after the connecting arm has forced it open, and a copper heater N, about five feet long, filled with burning charcoal, passes over the composition and melts it, thus leaving the valve air-tight as before, and ready

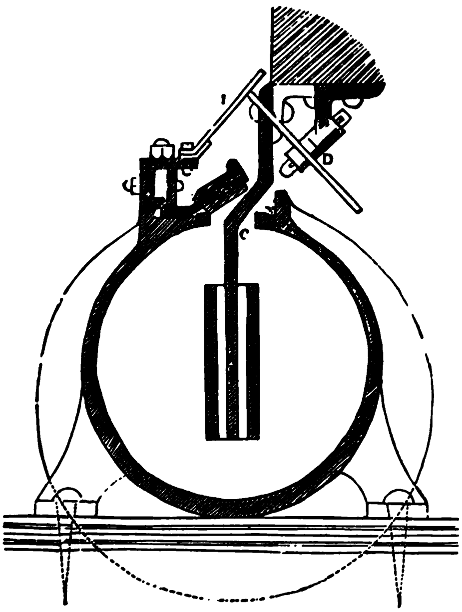


fig. 74.

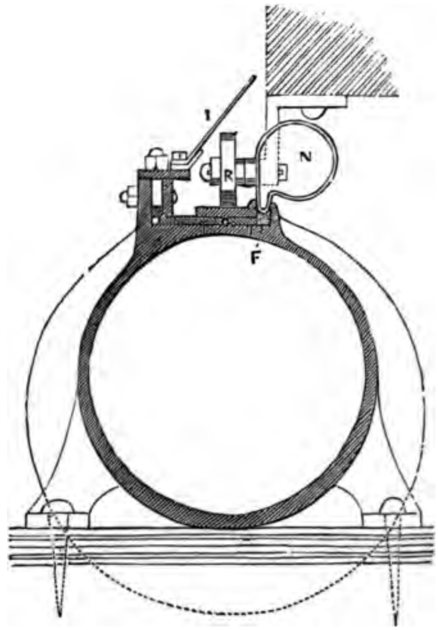


fig. 75.

for the next train. A protecting cover I, formed of thin plates of iron about five feet long, and hinged with leather, is placed over the valve to protect it from rain or dust. It is contemplated to have each pipe about three miles long, with a stationary engine for each length of piping to exhaust the air; and an arrangement is made by means of which the piston, as it approaches the end of the pipe, opens a valve which admits it into the next length of piping, so that the train may proceed from the one to the other without stopping.

" It is evident that as the tractive force is derived entirely from the pressure of the atmosphere on the piston, its amount will depend on the area of the piston, and on the extent to which the exhaustion of the air can be carried by the air-pump. It must also be evident that the difficulty of keeping the pipe air-tight will increase with its length, and with the pressure obtained. The vacuum-pipe on the branch of the Birmingham, Bristol, and Thames Junction Railway, where the atmospheric system has been in operation for more than three years, is only nine inches internal diameter, and but half a mile long. A part is on an incline of 1 in 120, and part 1 in 115. A vacuum equal in some instances to a column of mercury 23½ inches high has been obtained, and loads of 13 tons have been propelled at a speed of 20 miles an hour. On the Dalkey branch of the Dublin and Kingstown Railway, the pipe is 15 inches in diameter, and its length, so far as it has been tried, is one mile and a quarter. The

average incline is 1 in 100; the exhaustion has been extended to 22½

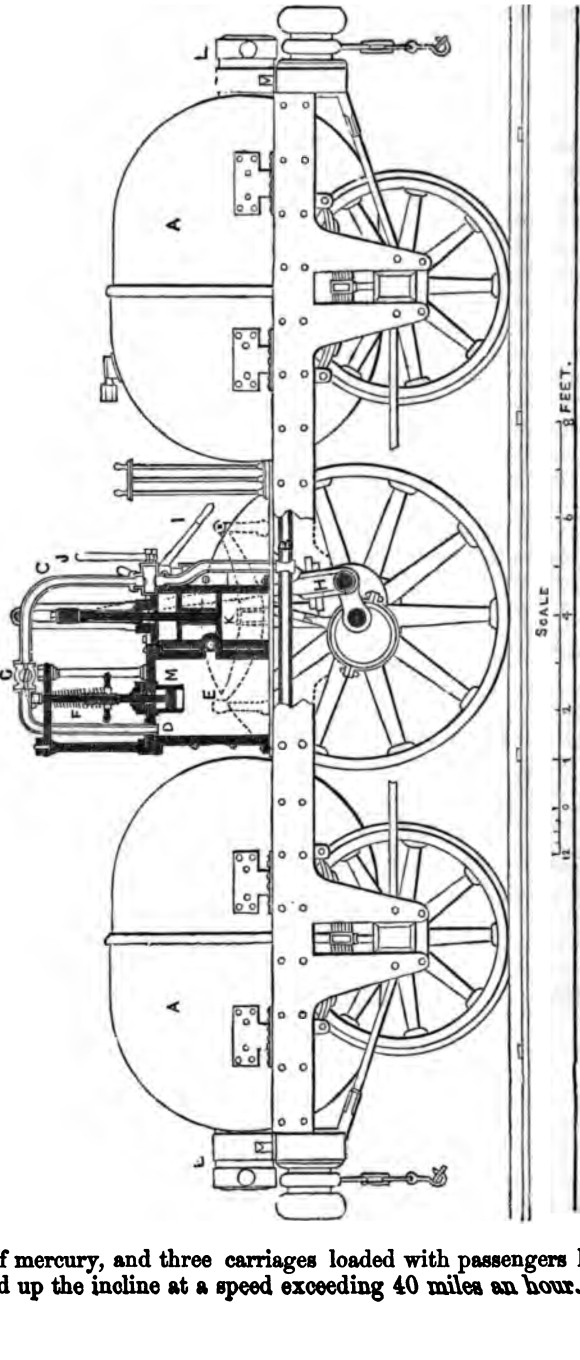


fig. 76.

inches of mercury, and three carriages loaded with passengers have been propelled up the incline at a speed exceeding 40 miles an hour.

"A stationary engine of 110-horse power would, it is stated, be adequate to exhaust a pipe of 18 inches in diameter, 2½ miles long, in four minutes; and trains might be started each way every quarter of an hour, and convey daily 5000 tons.

"In point of safety, the atmospheric plan seems far preferable to the locomotive. No collision of trains could take place while travelling on the rails. The only possibility of such accidents occurring would be at the junctions of the pipe, and by nothing short of wilful negligence could they happen even there."

Recently, at the Polytechnic Institution, there was exhibited a working model of a clever application of the atmospheric principle invented by a mechanic named Weston; and many visitors, both young and old, enjoyed a ride on its carriages the length and back again of the building. The system entirely reversed the modes we have been describing, by inverting the order of the whole arrangement; for, instead of a tube fixed on the railway, it was attached to the carriages or rather train underneath, and had moveable ends, and instead of a piston attached to the train a series of double-headed pistons were fixed on the railway. The pistons were supported on hollow stems, and connected with a main similar to a gas or water main laid along the line of railway; stationary engines, at suitable distances, were to pump the air from the main, and keep it in a state of partial vacuum during the time the trains were running. The engines having pumped the air from the main, a valve was opened by the driver at the fore end of the piston, when the air contained in the tube rushed through the piston down the hollow stem into the vacuum main, and a partial vacuum being thus produced in the tube, it was urged forward by the pressure of the atmosphere on the external surface of the valve at the other end of the tube. In this manner it was propelled from piston to piston. From the disfavour in which the atmospheric principle is held, we have not heard of this plan being attempted on a large scale.

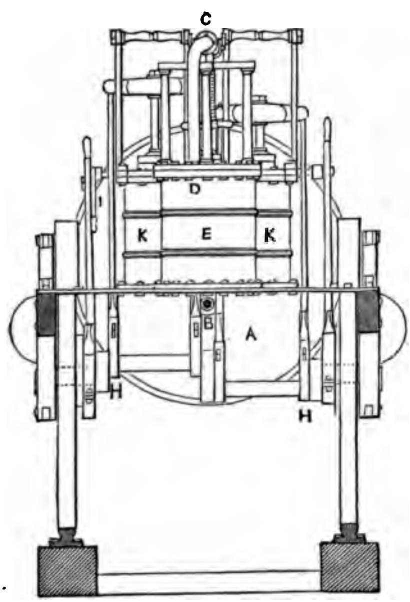


fig. 77.

In 1846 Mr. Parsey exhibited in London a model of a locomotive air-engine which he had patented.

Fig. 76 is a side elevation of the entire carriage, with the working parts of the engine shewn in section. Fig. 77 is an end elevation of ditto; and fig. 78 a plan of engine and part of air-vessels; the letters of reference corresponding in each diagram.

A A are receivers of compressed air; B, a tube connecting the receivers, from which the air passes up the supply-pipe C into the equalising cylinder E at D. Attached to the top of the equalising cylinder E is a self-acting apparatus for adjusting the supply

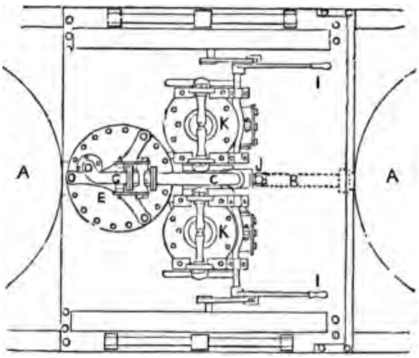


fig 78.

of air to the working cylinders K K; this is effected by setting the spring F so as to press down the valve M with a force equal to that at which the engine is to be worked, say 60 lbs. per inch. Whenever, therefore, the pressure in E becomes greater than that, the valve M is forced up, and partially closes the valve G; thereby limiting the supply from the receivers A A, and preserving a uniform pressure in E. The condensed air is conducted into the working cylinders K K through the sliding-valves, in the same manner as steam, and is admitted or shut off by raising or depressing the handle of the stop-cock J. Motion is communicated from the cross-head direct to the crank-axle of the driving wheels by the connecting rods H H. L L are for connecting the hose or pipe of the stationary reservoirs with the receivers, when a fresh supply of condensed air is required.

The inventor proposed constructing the receivers A A of his air-engine so as to sustain a pressure of from 1000 lbs. to 2000 lbs. per square inch; whilst the working pressure supplied to the engine from the equalising cylinder would be 60 lbs. per inch. But this could be increased, and the speed thereby varied from twenty to a rate equal to a hundred miles per hour. One charge to suffice to drive an engine fifty miles, with a train of 40 tons attached.

It was also proposed to erect stationary engines on a railway line, at intervals of about thirty miles; from these a fresh service of air could be obtained as readily as the engines are at present supplied from the water cranes. Mr. Parsey stated that the first cost of the engines, and the working of them, would be about half of the present expense of ordinary locomotives, while there was the advantage of tenders being unnecessary.

These inventions, doubtless, are very ingenious; they are the wonders of the day, but die a natural death, and are entombed among the numberless fruitless creations of man's busy brain. Compressed air will give out no more power than that expended in producing the compression, from which also has to be deducted the power necessary to overcome friction; but besides this there is another serious drawback that the enthusiastic inventor appears to overlook: on compressing air into a vessel a considerable amount of latent heat is roused into action, the natural consequence of which is a tendency to expand the air in the vessel, hence that expansion offers a resistance, to conquer which more power has to be applied that will not be returned; there is in fact, then, both the compression and expansion to be subdued. Again, on the compressed air being allowed to come in contact with the atmosphere cold is produced, as we know when we contract the muscles of the chest, narrow the orifice of the mouth, and eject the air of the lungs with force; therefore there is at once a positive loss in air-machines, as the power generated by the heat, which had power expended upon it that it might be subdued, is entirely lost. The want of

attention to simple principles has caused much labour to be fruitlessly expended.

fig. 79.

THE SYPHON.

Every one must have observed, in passing along the streets when the great wagons of the distillers are standing opposite some spirit-shop, this instrument in action, being employed in emptying the huge casks.

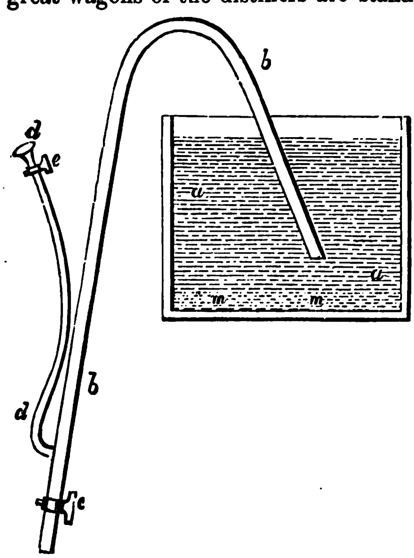


fig. 80.

The syphon is a bent tube *b b* having two legs of unequal length. When used, the shorter leg is inserted into the bung-hole of a cask or other vessel *a a* from which it is desired to draw off the liquid it contains. The tap *c* is first closed, then the mouth of a person is applied to a small pipe *d d* to create a vacuum, or the syphon is previously filled with liquid. From the pressure of the atmospheric air on the surface of the liquid it rushes into the syphon, when the tap *e* of the small pipe is closed and that of the larger one *c* opened; the liquid then flows out as long as the short leg is beneath the surface

of the liquid, and the extremity of the long leg is at a lower level. By this contrivance, the vessel to be emptied need not be moved, and any sediment, as at *m m*, remains undisturbed. The weight of the liquid in the longer leg falling from its own gravity would leave a vacuum, did not the pressure of the air in the cask or vessel force the liquid up and supply its place.

Sometimes syphons are formed on a very large scale for supplying towns with water or draining ponds or lakes, but the same law exists with regard to them as the pump; that is, they must not rise above thirty-two feet from the surface of the water, for beyond this point the fluid will not flow.

If a syphon, or rather bent tube, have two legs of equal length, and it be filled with water and turned downwards into water, the fluid will not run off as in the syphon described above; but if a small inclination be given, then one leg in effect is made longer than the other, and the water will flow off as long as there is any water remaining in the vessel. The reason of the water not flowing when the legs are equally long is, that the pressure of the atmosphere acts equally on both ends of the tube; but by shortening one of the legs the balance is destroyed, and the weight of the longest column of water preponderating pulls the other after it.

The principle of the syphon may be seen in loading a barge, when it is lower than the wharf, with a long small chain, or in placing it in a ship's hold. The chain being coiled near to the vessel a part of it is dropped down, when the weight of the long hanging piece drags the other immediately after it, acting as the long leg of the syphon upon the shorter one. We know, likewise, if a chain or rope be hanging over a high beam, when the two parts are equal it is at rest; but once make one longer than the other, then the long one drags the other pretty quickly after it. The water, therefore, in a syphon may be compared to a chain of water, the weight of the longer leg dragging the accumulated water off in a stream or chain, the pressure of the water preventing this liquid chain from breaking.

Mitscherlich contrived a very neat little syphon, fig. 81, for operative chemists, that they might draw off a liquid from above downwards without disturbing any sediment *d* that might be in the vessel. It consists of a bent tube *b c*, having legs of unequal length; that which is the shortest, and the one to be inserted in the liquid, is bent upward at the end *c*, so that the liquid flows into it from above, and does not in the slightest affect that below. The finger is placed on *b*, when the instrument is intended to be used, and the air being drawn out by sucking at *h*, the liquor flows in, and the finger being removed, it runs out at *b*.

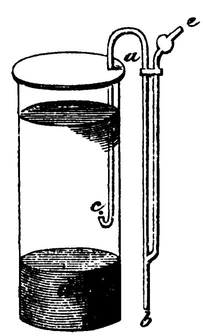


fig 81.


fig. 82.

The *dipping syphon*, fig. 82, is in common use where the contents of barrels or other vessels have to be tasted and there is no preparation for drawing off the liquid; it is a small narrow tubular vessel open at both ends, but contracted at the extremity and neck. On dipping it

into the barrel or vessel, the liquid enters and fills it, the thumb is then placed on the hole at the top of the neck, and being drawn out, none of the liquor escapes until the thumb is removed: upon doing so, a glass or other vessel can be filled.

Nature in the bowels of the earth has formed drains upon the syphon principle, which supply fresh water from some hidden reservoir.

We cannot leave this subject without noticing the pleasing toy called Tantalus's cup. The poor fellow stands up to his neck in water, as described in the fable, and whenever the water is brought to the level of his chin, and he is about to quench his unbearable thirst, the water vanishes. This is accomplished by the figure having within it a concealed syphon. The longer leg passes through the bottom of the cup in which the figure is placed, and the water is made to stand not quite so high as the bend of the syphon; therefore upon raising the water to the lips, it is over the bend of the tube, and runs out until the vessel is empty. A trick is also sometimes played, by having a syphon concealed in the handle of a drinking vessel, and upon asking a person to partake of the contents, when in the act of placing it to the mouth, it recedes, and disappointment ensues.

In decanting a bottle of wine, the air enters at one side of the neck, and thus allows the wine to pass out. If a tap be driven into a full barrel, the liquor will only dribble out; but if a small hole be made on the part uppermost, then the pressure of the admitted air forces it freely out of the tap. A large hole, on the same principle as the bottle, permits air to find its way in, and then a barrel may be speedily emptied without a vent-hole.

The spigot is now discontinued in many establishments, and a simple, neat, and improved plan has been substituted. A small pipe is inserted in the spigot hole, the other end of which is made to penetrate the cork of a bottle containing a solution of carbonic acid gas; this flowing into the cask, presses upon the liquid, and forces it out of the tap, adding at the same time a briskness that is gratifying to the imbiber, while it gives an improved character to the fluid itself.

THE BAROMETER.

The fact we have related in the preceding chapter, of thirty feet of water balancing the pressure of the atmosphere, was discovered by the celebrated Galileo. Some pump-makers, employed by the Duke of Tuscany, finding they could not raise water above thirty feet, in their dilemma applied for assistance to the philosopher, who proved to them that the law of nature did not permit of water rising above a certain height in a cylinder from which the air had been exhausted. Not only on the discovery of the pressure of the atmosphere, but on other philosophical subjects did Galileo contend against the prejudices and ignorance of the time in which he lived. Evangelista Torricelli, who was a young man residing at Rome, watched with deep interest the many important truths elucidated and published by the venerable Galileo; and writing two tracts, one on the motion of fluids, and the other on mechanics, he received from the aged philosopher an invitation to come to Florence. Shortly afterwards Galileo died, and Torricelli, at the age of thirty-nine, succeeded to the chair of mathematics in the noted academy of that city. Torricelli, in wishing to establish the truth of the pressure of the atmosphere, used, as

more convenient for experiment, mercury instead of water, making an allowance for the increase of weight, which is about thirteen times that of water.

He took a glass tube as at *a*, one end of which was hermetically sealed, and having filled it with mercury, the open end he carefully placed in a vessel *b b* containing the same material. On doing this, he noticed the mercury escaped from the glass tube until it stood at *c c*, a height a little more than 29 inches above the vessel of mercury in which the open end of the tube was placed. Thus, then, if the pressure of the atmosphere supported mercury a little over 29 inches, by multiplying that height by the extra weight of the mercury to that of water $13\frac{1}{2}$, he got the result stated by Galileo of about thirty-two feet. Then to prove that atmospheric pressure varied under different circumstances, he made the same experiment on the tops of high buildings and the summits of mountains. Thus the world was benefited by the great discovery of the barometer. The variation of the mercury on coming storms and hot weather was remarked, and its important application to the wants of man on sea or land rendered apparent. To the shepherd in saving his flocks, to the farmer in storing his hay or corn, and to the sailor in preserving his ship and crew, the barometer is invaluable; for though all may be serene and sunshine, not a speck in the ethereal vault of heaven, the faithful monitor will give note of coming danger.

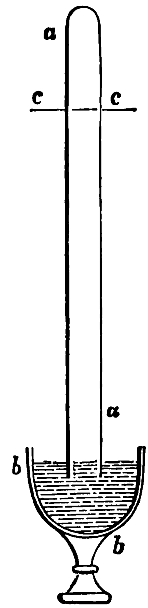


fig. 83.

We cannot here refrain from remarking, that upon any new discovery in science being first announced, there arises an incessant clamour, distressing to the elevated mind that gave birth to the discovery, of *cui bono?* (What is it good for?) Had this question been put to the philosophic Torricelli, when he discovered the barometer, we may venture to say he would have been puzzled to find an answer: the voices of all mankind can now proclaim innumerable benefits. When Franklin was asked the use of the discovery of atmospheric electricity, he asked in reply the use of a new-born infant. Many ridicule the careful minute observations of the daily and nightly magnetic variations at the Royal Observatory, Greenwich, and cry out—*cui bono?* No answer is given, and it is at once set down as a piece of pedantic folly. The first business of a learned man is to collect a mass of facts, and then, from a knowledge of the science, eventually apply them to a useful purpose.

We may here relate a circumstance strikingly illustrative of the practical value of the barometer. Three vessels were sailing in the Chinese seas in 1847 in very calm weather. The first vessel suddenly hauled in every sail, and made all snug. The singularity of this act, apparently without any reason for so doing, struck the mariners on board the second ship with astonishment, and the mate and captain consulted as to the strange conduct, when it flashed upon the former to hasten to the cabin and look at the barometer; and in fright he shouted out it had suddenly sunk an inch. Every hand was instantly at work, and in a few minutes the vessel was under bare poles. They now turned their attention to the last vessel, and on looking, saw every officer with his telescope attempting

to define the cause for such a remarkable and rapid manœuvre. Seeing they did not follow their example, the captain signalled to them the impending danger, and at once they began to take in sail; but it was too late, a terrific typhoon swept over the ocean—the azure sea became a mass of white foam—the vessels were whirled about like chaff. As soon as possible they looked for their companions; the first was safe, the other had found a watery grave. The nautical gentleman who witnessed this scene could have given a more satisfactory reply to the questioners of Torricelli than the inventor himself.

The barometer (which means a *weight measure*) consists of a narrow glass tube, about 34 inches long, closed at the top, having a small bulb of mercury at the lower end; this is placed upright in a frame, according to taste, and from 5 to 6 inches exposed to view, on which part are figures indicating the number of inches from the mercury at the bottom of the tube, and the words fair, change, wind, rain, stormy, &c.

Others are termed wheel-barometers; these have a bent tube C K B to hold the mercury, on the top of which is a small float E, having a silken thread A attached, passing over a pulley Q, and balanced by a little plummet R. On the rise or fall of the mercury, the thread turns a small pointer H, which indicates the various changes, as they are marked on a dial L, similar to the face of a clock.

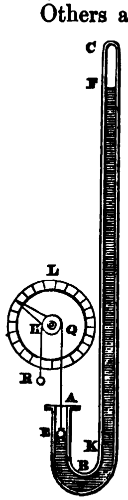


fig. 84.

In England, the ordinary range of the mercury is from 29 to 30 inches, and its greatest 3 inches; in Russia, 3½ inches. Near the tropics there is little or no variation; at Jamaica seldom more than three-tenths of an inch; and at Naples about 1 inch.

For minute observation, there is a little graduated index called a vernier affixed, which shews the fluctuation of the mercury to the hundredth part of an inch.

The barometer, as a *weather glass*, cannot be said to give an invariable rule; it merely shews that a change is taking place from the former condition of the atmosphere. When the mercury rises, fair weather may be expected, and when it falls, rain, snow, and storms; when it falls very low, it presages great winds, though not necessarily rain. In summer, when the mercury descends, thunder may be expected; in winter, when it rises, frost; a fall during frost indicates a thaw, and a rise, snow. If the change in weather follows closely upon that of the mercury, then such change will be of short duration. When mercury falls quickly, it indicates wind; and if it fall half an inch in an hour in London, and immediately change its direction, there may be expected a wind with a velocity of nearly 60 miles an hour. If there be a sudden fall of the mercury, and no particular immediate change, by noting the direction of the wind some hours afterwards, the situation of the storm that occurred may be known; and if the time from the falling of the mercury to the changing of the wind be noted, the exact distance of the storm may be calculated. For the atmosphere at that place having become rarefied, the air moves rapidly from all parts to fill up the partial vacuum, as air is drawn to a fire-place by the heat. This was beautifully illustrated in the Great Exhibition, where the direction of the wind in all the principal towns was shewn by the position of

little arrows, the information being daily transmitted by electric telegraph. The theory stated above was carefully watched by Mr. Holmes; and he became perfectly satisfied, by demonstration, of its truth. The same scientific gentleman considers that every storm has a similar one at its antipode; now storms being excited by electricity, it is possible that one may exist at a positive and one at a negative point. The observations, as yet, are too few to establish the fact; but as far as at present known, they are corroborative.

Barometers are employed for measuring heights. At the level of the sea the mercury stands, say at 29 inches and five-tenths; and at a height of 500 feet, it is found to have sunk half an inch. At $3\frac{1}{2}$ miles it is 15 inches, or nearly one-half; and at the height of 4 miles, it is only 12 inches high. This proves that one-half of our atmosphere is within $3\frac{1}{2}$ miles of the earth's surface.

In 1844 an *aneroid barometer* was patented, which instead of being dependent on the pressure of the atmosphere on mercury, the variations were pointed out by the pressure of the air on laminæ or diaphragms, consisting of thin sheets of metal, glass, caoutchouc, or other elastic substances; more especially a thin piece of copper-sheet corrugated circularly, so as to be sensible of the slightest pressure. A dial-plate with index pointers is placed over the diaphragm. A brass box, from which the air is extracted, is covered over by this elastic substance, supported from the pressure of the air by a number of delicate spiral springs fixed to the bottom. When the atmosphere becomes heavy, the springs sink, and move the index hands; and when light, the springs become more lengthened, which change is also indicated. This new barometer has not yet been sufficiently tested by scientific men to justify a decided opinion of its merits; but it certainly does not possess the simplicity of the mercurial barometer, which in principle is a common lever. At any rate it shews the wonderful elasticity of the atmosphere. The atmosphere is acted upon by gravity, and its weight is greatest at the surface of the earth, and less the higher we ascend. The invention of the barometer decided its exact weight. To prove that this is the cause of the mercury standing in the tube of the barometer, it is common to place the tube in a basin of mercury, under the receiver of an air-pump, when at every turn of the handle the mercury sinks; and if all the air be removed from the surface of the mercury, the height of that in the tube and basin will be the same. When the air is allowed to enter, then the mercury rises in the tube to its usual height. The pressure of the atmosphere is thereby proved to be equal to a column of mercury 30 inches high; now if it be calculated at 1 inch square at its base, that will be 30 cubic inches of mercury; and as a cubic inch of mercury weighs 7·85 ounces, this multiplied by thirty is equal to 235·5 ounces, or 14·9 pounds. We commonly say, therefore, that the atmosphere at the earth's surface presses on all things it touches with a weight of 15 lb. on every square inch. Hence the weight of the atmosphere is the same as if the whole globe was covered with a skin of mercury 30 inches thick. Again, this weight is equal to a solid globe of lead 20 miles in diameter, which if we had to move, we should hardly use the flippant expression of "as light as air."

The atmospheric pressure, upwards of 13 tons, on the body of a man, is not felt because air penetrates every part of the human body and

presses equally in all directions. When he ascends a high mountain, as some adventurous persons did lately by going to the top of Mont Blanc, he finds a difficulty of breathing, from the air being less dense than he has been accustomed to. Every thing on earth, liquid and solid, is thus compressed and kept in its position and form; were this pressure removed, things would assume different forms, and probably many that of the gaseous state, as most persons know is the case with ether and alcohol. To overcome this atmospheric pressure, and separate the atoms of matter in many fluids, man applies heat, and it is necessary to note the various degrees of heat required to be applied to different fluids to raise them to what is termed the boiling-point. At the earth's surface, that is, where the mercury in a barometer stands at thirty inches, the heat required to boil ether would be by Fahrenheit's thermometer 190 degrees, to boil alcohol 174 degrees, water 212 degrees, oil and tallow 600 degrees, and mercury 650 degrees. By ascending a mountain the pressure of the atmosphere is lessened, and consequently less heat is required; for instance, at Quito, 10,000 feet above the level of the sea, water boils at 194 degrees, and on Mont Blanc only 180 degrees of heat are necessary to boil water, and by this test the actual height from the level of the sea may be ascertained; while in a diving-bell 68 feet deep in water it requires a heat of 272 degrees to make water boil.

The experiment of boiling fluids freed from the weight of the air has been tested by means of the air-pump; when it was found that water would boil at a less temperature than blood-heat by three degrees, and ether when six degrees above the freezing-point of water. This fact has, like most scientific knowledge, been rendered serviceable to man, most remarkably so in the distilling of drugs and the refining of sugar. By reducing the pressure of air, the pure medicinal properties of one have been preserved; in the other, a saving of material and superiority of quality.

The celebrated Dr. Papin, crossing the Great St. Bernard, stopped at the famous alpine monastery, when the monks, desirous of shewing their hospitality, asked him if he had any preference as to the mode in which his food was cooked, when he replied that he preferred boiled to roasted meat. The holy brethren informed him in this particular they were sorry they could not oblige him, as, from some natural cause, meat would not boil at such an elevation. Upon the doctor returning to Paris he pondered over the subject, and the result was the invention of his famed digester, which gave an impetus to the application of steam as a moving power: one of these digesters he had the satisfaction of presenting on another visit to the monastery, much to the delight of the pious fraternity.

The reason of this difficulty in cookery was the small amount of heat required to boil water at such an elevation not being sufficient to perform the necessary cooking operation, and the meat consequently was raw. The digester did not allow the steam to escape, and thus heat was accumulated until even bones were dissolved. It is proper to state that for the sake of safety Papin adopted a valve to his invention, so that it opened when the steam was likely to be too stro ng for the iron of which the vessel was constructed.

We may mention a very beautiful experiment by which some of our juvenile readers may astonish their companions, in making water boil in

a bottle on placing it in a vessel of cold water. This is effected by pouring a little water into a Florence flask and holding it over a spirit-lamp until it boils; when the steam is briskly issuing from the neck of the flask, cork it tightly, and remove it from the lamp. The action of boiling will then have ceased, but on placing the flask in cold water it will boil with great rapidity; remove it from the cold water to the lamp, and the boiling ceases; place it again in the cold water, and it again boils.

The cause of this is, that the cold water condenses the steam, and from the vacuum produced the water boils; when placed over the lamp the flask is filled with steam, there is no vacuum, and the water no longer boils from the pressure.

It would be appropriate to our present subject here to introduce the *steam-engine;* but a machine so complicated in its various parts, so multitudinous in its details, so necessary for all to understand its mechanism, fraught as it is with such important considerations to man, and entering into the affairs of his daily existence in civilised society, would occupy, to do it justice, the whole extent of the present work, and therefore must be left to a separate treatise. Still, to treat as perfectly as our limits allow the subject of this volume, we will state the principle upon which the mighty machine acts, and give a popular account of steam.

Steam, which man in his ingenuity creates and binds down by iron bands, harnesses, and renders subservient to his wants, is a dry, transparent, colourless, invisible substance. By heating water he separates its atoms and gains this imperceptible irresistible power. What we see and call steam issuing in fleecy clouds from the spout of a tea-kettle is steam in a state of condensation, that is, returning again to its previous state of water by meeting with air colder than 212 degrees: if steam be collected in a vessel heated to 212 degrees, then it is invisible to the human eye, like the atmospheric ocean in which man lives.

When heat is applied to the bottom of a vessel the air previously contained in the water is first driven out; this is considerable, as water always imbibes, when exposed to the atmosphere, its own bulk of that substance. On water arriving at the boiling-point it dissipates as vapour into the atmosphere—being then in that condition called steam. When the vessel in which water is boiled is very deep, the heat applied to the bottom of such vessel does not make the water at the bottom hotter than at the surface, because the water which is heated expands, becomes lighter, and floats, its place being taken by the portions at the surface cooled by the evaporation. Should, however, the heat be applied at an intermediate part between the surface and the bottom, all the water above the fire will be raised to the boiling-point, or even higher, under pressure, while the water at the lower part of the vessel will remain comparatively cool. Therefore in steam-boilers the heat is frequently applied to the interior of the boiler, for the purpose of boiling the upper portion of the water quickly.

The noise of water about to boil, called *singing*, arises from the force with which the air is flying off from the water.

"A pint of water," says Dr. Lardner, "may be evaporated by two ounces of coal. In its evaporation it swells into two hundred and sixteen gallons of steam, with a mechanical force sufficient to raise a weight of thirty-seven tons a foot high. The steam thus produced has a pressure equal to that

of one atmosphere; and by allowing it to expand, by virtue of its elasticity, a further mechanical force may be obtained, at least equal in amount to the former. A pint of water, therefore, and two ounces of common coal, are thus rendered capable of doing as much work as is equivalent to seventy-four tons raised a foot high. . . . A pound of coke burned in a locomotive engine will evaporate about five pints of water. In their evaporation they will exert a mechanical force sufficient to draw two tons weight on the railway a distance of one mile in two minutes. Four horses working in a stage-coach on a common road are necessary to draw the same weight the same distance in six minutes."

At the heat of 212 degrees the force of steam is 15 lbs. on the square inch against a vacuum; at $251\frac{1}{2}$ degrees 30 lbs.; at 272 degrees 45 lbs.; and at 290 degrees it has an elastic force of 60 lbs. on the square inch. This last requires about four times the same quantity of water as the first to form it. With such an awful power it behoves all concerned to be careful of the strength of the vessel in which it is to be confined, and a proper arrangement of valves; the neglect of these precautions has led to terrific accidents, and produced a fear of a power as easily controllable as the most simple object in the service of man.

In speaking of the power of steam, it is usual to say it has a pressure of so many atmospheres; for instance, as we have before stated, the weight of the atmosphere is about 15 lbs. on a square inch. As at 212 degrees the steam exactly balances the atmosphere, on steam-gauges it is marked zero. When steam is at double that pressure, or opposite $251\frac{1}{2}$, the gauge is marked 1, or 15 lbs., or one atmosphere above the external atmosphere; at 272 degrees, a pressure of 30 lbs., or two atmospheres; and so on, every 15 lbs. being an atmosphere.

One cubic inch of water, when converted into steam, occupies a space of nearly 1 cubic foot, actually 1696 cubic inches, at the pressure of the atmosphere; but at the pressure of two atmospheres, it only occupies half the space; and so on.

Water contains, as other substances also, a certain degree of latent or hidden heat, and in changing its form from the liquid to the gaseous state it absorbs more. Water, when passing from the solid to the liquid state, by the thermometer is shewn to be at 32 degrees; and when raised to the boiling-point, is at 212 degrees, which is an addition of 180 degrees; but to turn the boiling water into steam requires nearly six times this quantity of heat. If the 180 be multiplied by $5\frac{5}{9}$, the result is 1000; and this is the quantity of latent heat necessary. This heat absorbed by the steam cannot be discovered by the thermometer, and is therefore termed latent or hidden; but if the steam be returned into water, it is then given out. This is shewn by the time and fuel necessary in raising a certain quantity of water into steam; and proved by a pint of water formed into steam raising nearly six pints, when commingled, to the boiling point.

This gradual absorption of latent heat is one of those wonderfully careful provisions of nature that surprises the puny intellect of boastful man, as it prevents those sudden changes by which destruction to the harmony of the earth would be terrible and incessant. That admirable invention the *steam-engine*, the helpmate of man, that will carry on all the multitudinous operations of a manufactory, that with the slightest attention will

even regulate its own necessities, is simple in principle. It consists first of a boiler, in which the water is converted into steam; from the boiler proceeds a pipe, along which the steam passes into a chamber which has valves at the top and bottom communicating with the cylinder, in which the piston moves up and down; if the piston be at the top of the cylinder, and the whole of the space below filled with steam, the steam-valve above the piston will be open, and the bottom one be closed. At the same time, another valve called an exhausting valve, at the bottom, will be opened; the steam then admitted above the piston will drive it down, while the steam below will escape by the exhausting valve, and be condensed into water. The steam-valve above now closes, and the exhausting valve opens; while the lower exhausting valve closes, and the lower steam-valve opens, which drives the piston back again; and thus the action goes on up and down. The top of the piston-rod is affixed to such cranks or other things as may direct the power as required. There are innumerable ingenious contrivances connected with each part both of the boiler and the engine. Thus in the boiler there is a feed-pipe, by which the condensed and heated water which has done its duty as steam is admitted as required into the boiler by its own operation; a gauge to know the force of steam; a safety-valve to open when the steam has too much pressure; gauge-cocks to know the quantity of water in the boiler; and a man-hole to get in and clean out the inside. Below the cylinder, containing the piston of the engine, are two cylinders, one of them immersed in a cold water cistern; the steam that has been used is forced into one in which cold water rushes through a pipe, having at its extremity a rose like that of a watering-pot, that condenses the steam; another cylinder, by the side of the steam-cylinder, is an air-pump, which operates like a common pump, and draws off the surplus water from the cylinder in which the steam was condensed; another pump then conveys the water to the reservoir, from which the feed-pipe proceeds.

The *governor*, which resembles a pair of tongs with the legs stretched out, regulates the quantity of steam admitted to the engine; should there be too much, the legs fly apart, and, by a contrivance, close a valve in the pipe which admits the steam to the cylinder.

The *fly-wheel* gives regularity of motion to the machine, and prevents any check upon its motion.

The *eccentric* is connected with the engine, and opens and shuts the valves by which the used steam escapes and fresh steam is admitted.

Attached to different parts are numerous rods, by which the engine becomes self-acting and self-adjusting, marks the number of its strokes, supplies its boiler with water, feeds itself with coal, takes oil when necessary, with a damper regulates its heat, will slacken the fire with water, and in helplessness rings a bell to call for its attendant's aid. What writer of fable ever conceived such marvels? Almost to a truth is it what the rhymester says:

"I've no muscle to weary, no breast to decay,
No bones to be 'laid on the shelf;'
And soon I intend you may 'go and play,'
While I manage the world myself."

The temperature of the atmosphere causes various alterations of the humidity of the air, and by evaporation and condensation preserves that

genial and refreshing moisture which gives vigour to nature. Wherever there is moisture, and the air above is not overcharged with vapour, there is evaporation silently and unobservedly going on; and no sooner does the temperature become lowered, when the atmosphere contains an abundance of vapour, than it forms into water, and again descends. The beneficial effects of evaporation on the atmosphere are demonstrated by thus cooling the heat of a sick-room, or watering the streets during the heat of summer.

The moisture drawn up by the sun in summer is partially returned, on the earth turning from its great luminary, in the form of *mist* and *dews.* The mist is the precipitated vapour previously existing in an invisible state in the warm air; and as the cooling of the upper strata of air descends towards the earth, so the mist or precipitated vapour also descends, and at last reaching the surface of the earth, is deposited on the coolest substance, generally the leaves of plants and blades of grass, forming the beautiful translucent globules called *dew.* Should the night be cloudy, the heat reflected to the clouds by the earth is returned; then as the temperature between the two, under these circumstances, is nearly equal, there is little or no dew. Such is the perfect ordination of the Creator, that various trees and herbs possess different powers of attracting dew; and hence the formation of varied quantities, but each according to its individual requirements.

When air which is loaded with moisture rises, and then consequently has less pressure, in cooling and expanding it lets fall part of the vapour in the form of *rain;* and if carried very high, or the temperature near the earth be very low, then the released moisture becomes *snow.* The rising of smoke in chimneys is caused by the heated and rarefied air floating upwards through the more dense mass, till it arrives at a state of the atmosphere equal to its own density, carrying with it the small particles of the coal not consumed; these attain a particular height, and then fall again, as is discoverable in all towns by the dirt covering the windows, and the dust lying on furniture. On the same principle, when the air at the earth's surface becomes heated, it rises, and the colder and more dense air rushes into its place, which action constitutes what is termed *wind.* Now the sun is continually heating the air at the equator, and following the universal law, it rises, which creates a current of wind from the northern and southern regions, and these are what are so well known as the *trade winds;* but as the earth is whirling eastward, it makes the one to blow north-east, and the other south-east. When the sun is on the equator, these winds change as the position of the sun with regard to the earth is altered. The loftier currents of the atmosphere carry the heated air towards the poles, which in its passage becomes cooled. Winds may be termed strong currents of air.

In several parts of the eastern and southern oceans, the winds that blow are at particular periods in one direction, and are called *periodical;* they also are dependent on the sun, because from the end of March to the end of September the winds set in from the south-west, and the remainder of the year, when the sun is south of the equator, the wind blows from the north-east. These *monsoons* or shifting trade winds are the extremities of the influence of the trade winds in southern latitudes, nearly corresponding to our equinoctial gales in the northern extremities. During the changes,

occur those variable winds and terrible storms justly dreaded by our hardy navigators.

Between the tropics, on the greater part of the coasts the wind blows towards the sea at night and towards the shore in the daytime. How wonderful is this economy of nature, how beneficial to the human race! During the intense heat of the day the air over the heated land becomes rarefied and rises, while the cool air from the ocean flows in to supply its place; on the other hand, during the night the air in contact with the mountains and hills, being cooler even than that overhanging the sea, flows down into the valleys; thus there is a healthful equilibrium preserved, for which man may be thankful to his Maker. These are called *sea and land breezes*, and only take place where there is high land. This may be exemplified by putting in the middle of a large dish of cold water a saucer filled with hot water; the latter supposed to be the land, the former the sea. Take a candle which has just been blown out and hold it over the cold water, and the smoke will be seen to move towards the saucer containing the hot water. Again, fill the dish with hot water and the saucer with cold, then hold the extinguished candle over the saucer, and the smoke will move to the dish of hot water.

A lady from Demerara speaking to us of the land and sea breezes, said that although the thermometer stood many degrees in that country above that which it ever attains in this, yet that during the summer in London she suffered more from the effects of heat than she had experienced in Demerara, owing to the sea-breezes that waft over the land, while here a breath of air did not seem to exist in the atmosphere.

In this country exist what are called *variable winds;* changing often in the most rapid manner, the clouds passing in different directions to that felt at the earth's surface. Usually a south and west wind, which blows from the Atlantic, brings warmth and moisture; a north and east wind, cold and dryness. In Europe the south-west wind is most prevalent, and contains most moisture.

Much attention has been given by scientific men to the subject, and the following are the results they have arrived at:—

THE PREVAILING WINDS AT LONDON.

Winds	Days	Winds	Days
South-west	112	South-east	32
North-east	58	East	26
North-west	50	South	18
West	53	North	16

The south-west wind blows more upon an average in each month of the year than any other, particularly in July and August; the north-east prevails during January, March, April, May, and June, and is most unfrequent in February, July, September, and December; the north-west occurs more frequently from November to March, and less so in September and October, than in any other months.

Average of seven years, by Dr. Meek, near Glasgow:—

Winds	Days	Winds	Days
South-west	174	North-east	104
North-west	40	South-east	47

In Ireland the prevailing winds are the west and south-west.—If the wind veers about much, rain will ensue; if in changing it follows the course of the sun, it brings fair weather; the contrary, foul.

CAPTAIN BEAUFORT'S SCALE.

	Hourly velocity.		Hourly velocity.
Light air	0·1 mile	Moderate gale	30 miles
Light breeze	5 miles	Fresh gale	45
Gentle breeze	10	Strong gale	50
Moderate breeze	15	Heavy gale	70
Fresh breeze	20	Storm	80
Strong breeze	25	Hurricane	100, &c.

TABLE OF THE FORCE OF WIND.

The following table, in the Royal Polytechnic Institution of London, is considered by scientific men the most exact approximation to the force of wind :—

Velocity of the wind. Miles in an hour.	Feet in a second.	Perpendicular force on one foot area in pounds avoirdupois.	Common appellation of the force of the wind.
1	1·47	·005	Hardly perceptible.
2	2·93	·020	Just perceptible.
3	4·40	·044	
4	5·87	·079	Gentle pleasant wind.
5	7·33	·123	
10	14·67	·429	Pleasant brisk gale.
15	22·00	1·107	
20	29·34	1·968	Very brisk.
25	36·67	3·075	
30	44·01	4·429	High wind.
35	51·34	6·027	
40	58·68	7·873	Very high wind.
45	66·01	9·963	
50	73·35	12·300	Storm or tempest.
60	88·02	17·715	Great storm.
80	117·36	31·490	A hurricane.
100	146·70	49·200	A hurricane that tears up trees, carries buildings before it, &c. &c.

The principle of the lighter fluid floating up through a heavier one is exemplified in that useful apparatus found in the laboratory of the chemist, and seen in popular lectures on the science of chemistry—the *pneumatic trough.*

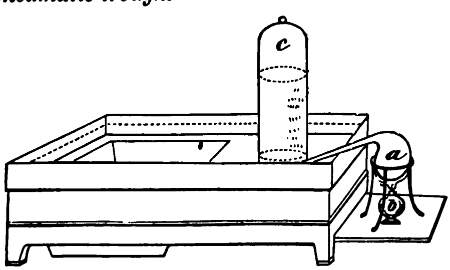


fig. 85.

The material from which it is desirable to evolve gas is placed in a retort *a* or other convenient apparatus, and sometimes heated by a spirit-lamp *b* or fire. The gas flows along the pipe-neck of the retort, the end of which is placed under water, and leaving the pipe, floats up through the water, enters the receiver *c*, displaces the water in it, and is thus collected for the purposes required by the experimenter. When it is desired to preserve the gas, or move it to a distance conveniently, most frequently a bladder is then screwed on to the top of the receiver, which being gradually sunk in water, the gas is pushed upwards into the bladder.

On a large scale, the operation we have just described is carried on in those gas-works which supply towns—the vessel which holds the gas being called a gasometer. This consists of a large cylindrical vessel *b b b*, made of sheet-iron and perfectly air-tight, suspended mouth downwards by chains *c c*, pulleys *d d*, and balance-weights *e e*, in a tank of water *a a*; the gas flows in through the water by means of pipes, and raises up the huge fabric. Other pipes are placed to conduct the gas to its destination,

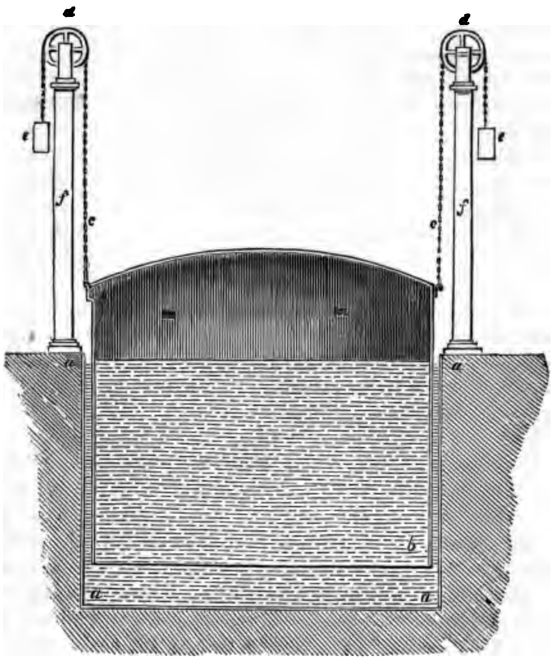


fig. 86.

which come out above the water, and by a contrivance a steady pressure is kept up to force the gas out, thus giving a continuous even light to all the consumers: *ff* are the pillars for supporting the pulleys; the gas occupies the top *m m* of the gasometer as it rises.

A philosophical mind observing some restless little embryo men amusing themselves, at the expense of sickness and an aching head, in mixing soap and water, and through a pipe blowing bubbles,—their simple minds overjoyed in watching the fragile and perfectly-formed globe of their creation ascend into space, tinted with the inimitable prismatic colours,—and noting, that if in this childish game the operation was performed with cold water the tiny globes speedily fell to the ground, and that the hotter the water the more quickly did they soar aloft, is said to have given the first idea of an air-balloon.

The first balloons that mounted into space were filled with air heated by a fire kept burning underneath the mouth of the silken bag: the idea being, by burning straw and other combustibles, that a cloud was being formed, caught, and held, so that a man might swing from it and take an aërial journey. When announced as successful, they were the wonder of the age;

the world rang with the great discovery, miracles were predicted as capable of being achieved by a flight into the ethereal ocean, while, as is often the case in scientific researches, the impiety of the act was denounced, and stated to be deserving the vengeance of the Almighty.

Man has been gratified in viewing places under an aspect he never could have done but for balloons. The benefit to society from their invention has been comparatively nothing, as no one has hitherto succeeded in guiding them; in the air they are the creatures of every current, and are driven by them, as found to exist. Gay Lussac, the celebrated French chemist, ascended to the height of 22,960 feet, upwards of four miles and a quarter, for the purpose of scientific investigation. His principal object was to ascertain if the magnetic influence existing at the earth's surface ceased at a certain elevation, but he could not discover any sensible difference. The air he also found to consist of the same elements as that of the lower strata. In 1852, four ascents were made by Mr. Welsh for scientific purposes, aided by a committee of learned men; in the last ascent the balloon attained a height of 23,000 feet above the sea, when the temperature was 10½ degrees below zero. Considerable difficulty was found in respiration, and there was a current of upwards of 60 miles an hour.

The hot-air balloons were succeeded by those filled with hydrogen gas; but upon the carburetted hydrogen used for the purpose of lighting towns being extensively manufactured, the aëronauts found it more advantageous to increase the size of their silken varnished bags, and fill them with common coal-gas, than have them smaller, and filled by the lighter gas of pure hydrogen.

It is found that a balloon when filled with gas is only the eighth of the weight of the surrounding atmosphere; thus if the weight of the quantity of cubic feet of common air necessary to fill a balloon was 1600 lbs., the same quantity of gas would only weigh 200 lbs.; then if the weight of the apparatus be another 200 lbs., the balloon would lift 1200 lbs. Should the balloon be filled before starting on its aërial voyage, the gas must be allowed to escape, as in its ascent it would expand and burst its silken prison. Not only has this point to be regarded by the managers, but, on being balanced in the air, the machine must be lightened by casting out ballast. On rising beyond a certain height the gas has again to be emitted, as the air is more rarefied, or the heat increases; thus, as the working of the machinery progresses, the power of buoyancy decreases, and a descent becomes necessary, requiring skill in effecting it safely.

The great Nassau balloon, constructed by the veteran aëronaut Green for navigating the aërial ocean, is 64 feet diameter, and when filled holds 80,000 cubic feet of gas. The weight of the silk is 80 lbs.; the greater cable and grappling-iron 3½ cwt., the smaller one 1½ cwt., both of which are taken up in rough weather; the iron ring to which the netting is affixed, and from which the car is suspended, is 3½ cwt.; the entire weight it will carry when loaded to the utmost is 6000 lbs.; if filled with pure hydrogen, it would carry up 40,000 lbs. The large cable is 3½ inches in circumference, and has india-rubber interwoven, that its elasticity may be increased. The greatest number of persons who have ascended in it at one time to enjoy the wonders and participate in the dangers of an aërial voyage, has been eighteen. A barometer, preserved with religious care by this skilful aëronaut, shews the mercury to have been as low as

seven and a half inches, which would give the height attained about six miles. He states the moisture in the higher regions to be in a frozen

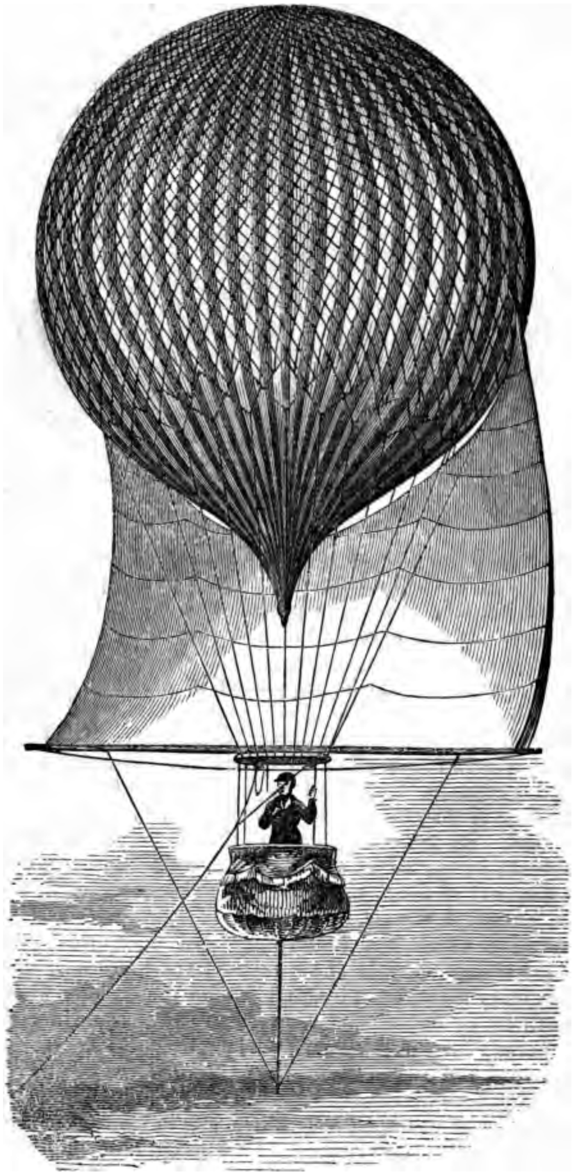


fig. 87.

state, as snow, and not as vapour, and that even on the finest and hottest day, when not a cloud was visible, the balloon was covered by eight inches of snow.

One of the latest attempts to govern these aërial machines was by Mr. Bell, who made the experiment in the summer of 1850. The machine was of a cylindrical form with conical ends, having its greatest length placed horizontally, or in the direction in which it was to travel. In place of the rope-netting in ordinary use, the patentee used flat silken bands, for the purpose of strengthening the balloon, and affording an attachment to the framework and car. These were placed longitudinally, transversely, and diagonally, round the balloon. Mr. Bell also introduced some improvements in the valve apparatus.

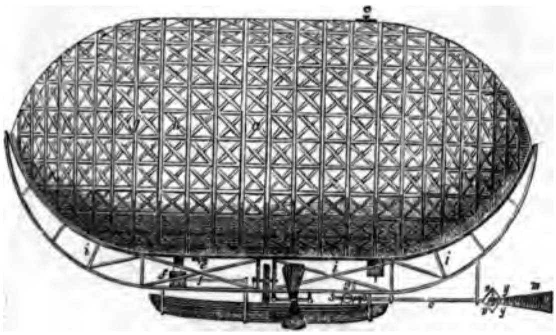


fig. 88.

The car was formed so as to fulfil the purposes of a canoe or boat, if required, and would, when a long voyage was contemplated, be provided with every requisite for sea. The propellers were on the principle of the screw-propeller. If two were to be used, they were placed one on each side of the car, as in the engraving; if but one, it was to be placed between the car and the balloon, supported in a strong but light framework, to which was attached the steering apparatus or tail (from its similarity to the tail of a bird). This apparatus was constructed so as to have a hinge and a rotating motion, to obtain the necessary movements of an extended surface or fan, in all respects similar to the tail of a bird, that the guiding or directing of the machine might be under the control of the aëronaut. By the combination of the above motions, the steering apparatus might be moved in any direction, either up or down, laterally, or in any diagonal of these, thus regulating the direction of the machine in its passage through the air.

The machine which Mr. Bell constructed upon this principle was capable of sustaining a weight of between 500 and 600 lbs., when inflated with the ordinary carburetted hydrogen. Its dimensions were about 50 feet in length by 22 feet diameter, made of the finest white silk, manufactured expressly for the purpose. The netting was composed of stout amber silk bands two inches wide. These were placed double and stitched together, having been previously carefully tested. After a long and wearisome preparation of the apparatus which was to effect the "locomotion," the balloon ascended in the presence of a considerable number of spectators—among them several individuals of scientific eminence. Mr. Bell himself was the only occupant of the car. The balloon, when it was fairly released from the tethers which held it to the ground, at once followed the course of the wind, in which direction it continued to travel The aëronaut did not seem to have any specific control over the machine, be-

yond that of turning it round. It drifted along the air like any other balloon; and it finally vanished from sight without any apparent retrogression.

In the illustration, the car *l* is placed parallel to, and fastened beneath, the buoyant apparatus *a* by the bands *g g*, placed longitudinally and transversely round the balloon *a a*, and diagonally, if great strength be required, as shewn in part, and stitched where they cross one another at *h*. *i i* is the framework of the balloon motor-machine, and is composed of metal tubes. *c* is the top emptying-valve. The tail apparatus is composed of a frame *m*, more or less in the form of a bird's tail, over which some membrane may be stretched; or it may be made wholly of metal. This is moved upon a hinge-joint *l* by means of a running cord or chain *y y*, passing from either surface of the tail-fan *m*, over pulleys on the ends of the branches of tubing *n n*, passing down into the axis-tubing *o*, through which it is conveyed, and fixed to the periphery of the wheel *p* situated at the extremity of this tubing, as represented in the framework; or it may be in the car or boat: by these means a complete hinge-motion is obtained. By turning the wheel *p* on its axis by the handle *s*, in either direction, the one cord will be taken up on the periphery, while the other will be slackened out, causing the extremity of the tail to depart from the straight line. The partial rotation of the whole tail apparatus, just mentioned, is effected by the motion of a small lever *q* attached to the arms on either side of the wheel in which its pivot works; the arms being firmly attached to the tubing *o* on which the hinge of the tail-fan *m* works. This tube is rotated by moving the lever *q* to either side, and hence it is called the axis-tube; the tube in which it has the rotary motion is marked *r*. Two ratchets or fixing-wheels *x* and *z*, for the purpose of securing the tail *m* in its different positions, are attached to the wheel, which is held at any required point by the click *x* 1, which adjusts the position of the tail on its hinge-motion (as before explained) by the cords *y y;* while the ratchet-wheel *z* with its tube *r* affixed to the framework, secures the whole apparatus in any position obtained by its rotation with the tube *o* by means of the click *z* 1.

Many have been struck by the awfully sublime calm of the heavenly regions, and the apparent insignificance of man—his pride and passions, his works and the spots where he clusters—when viewed even from the comparatively small height to which a balloon can rise.

HYDRAULICS.

THIS name is from two Greek words, meaning water and a pipe, and therefore strictly signifies the art of conveying water through pipes; it has, however, in science a wider range, teaching how to estimate the swiftness and force of fluids in motion, whether produced by natural or artificial means. In works on the subject it is stated as a rule, that

"The velocity with which water spouts out at a hole in the side or bottom of a vessel, is as the square root of the depth or distance of the hole below the surface of the water."

But we would remark that this rule is not quite correct in practice, owing to counter currents and friction.

In a former part of this work we pointed out the pressure of water

against the sides of any vessel that confined it, and that such pressure increased on the sides as the square of the depth of the water.

If two pieces of the same sized pipe be fixed in a vessel full of water, and one be placed four times as far from the surface of the water as the other, the lower one will deliver just twice as much water as the upper one, at nine times the depth a triple quantity, and so on; as the distance is increased from the surface, so is the quantity of water discharged increased. This is the same in principle as that which governs falling bodies; for were a short pipe fixed in the bottom of a vessel and turned upward, the fluid would spout up to the height of the surface of the water in the vessel, and leave the pipe with the same velocity as when falling it would attain on reaching the level of the pipe from whence it had issued. There are, of course, some allowances to be made for friction and the resistance of the air.

The facts we before arrived at respecting the pressure of fluids were, that the pressure on the bottom of a vessel, if the sides be perpendicular, is equal to the weight of the fluid; and as the pressure on any one side is equal to half the pressure on the bottom, when the sides and bottom are equal, the pressure on the four sides and bottom of a square vessel is equal to three times the weight of the fluid. Thus, if the water weighs 12 lbs., the pressure on each side of the vessel will be 6 lbs., which multiplied by the four sides is equal to 24 lbs., add to which the weight on the bottom 12 lbs., the total is 36 lbs. pressure, three times the weight of the fluid.

The pressure against the side of a vessel increases in proportion to the square of the depth; but in water spouting from a pipe the velocity increases as the square root of the depth; for if in a brewer's vat constantly kept full there were a pipe a foot below the surface, and it was desired to draw off the liquor from it 3 times quicker, another pipe would have to be placed 10 feet from the top, and if 4 times faster, 17 feet from the top, as before named.

In engineering the pressure of fluids is a consideration of vast importance, for calculations as to the requisite strength to resist the pressure in forming the banks of canals, the embankment of rivers, reservoirs, docks, tanks, and other works of skill. If, for instance, a reservoir has to be formed one yard deep, and another four yards deep, the last-named must be sixteen times stronger than the former at the bottom, because the pressure increases as the square of the depths.

The friction of water in pipes is found to be considerable, therefore the smoothest material is always chosen for their manufacture; and whenever practicable, when large supplies of water are needed, to reduce the friction, the pipes are made enormous in size. The friction in an inch pipe about 67 yards is found to have such effect, that only one-fourth of the water will be discharged that would pass direct from a hole of the same bore made in a thin vessel. The most advantageous application for the discharge of water is that of a short pipe, in length only twice its width or diameter.

If a pipe be protruded into the interior of a vessel, that is, not flush with the sides, the discharge of water is diminished. To aid a free egress of water it is useful to commence the pipe in a funnel-shape, as then the particles of the water do not so readily cross and impede each other.

Thus, in the figures annexed, where the vessel marked *a* is being emptied of its contained water, currents cross each other as indicated by the arrows, and much impede the rapid flow of the water; but in the figure marked *b*, having a funnel-shaped mouth, the water flows easily and rapidly, the sloping sides of the exit-pipe facilitating the flow.

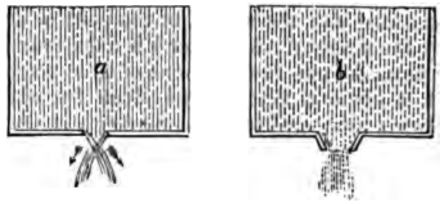


fig. 89.

It must be self-evident on the slightest reflection, that the velocity of water running out of a vessel which receives no additional supply will continually decrease, in proportion as the quantity lessens, from the surface becoming lower and the depth less. If a vessel were divided into 36 spaces, and would empty itself in 6 minutes, the water would descend through 11 of the spaces in the first minute, 9 in the second, 7 in the third, 5 in the fourth, 3 in the fifth, and 1 space in the sixth and last minute. If the vessel were kept full, it would discharge as much water in half the time.

The flow of water through orifices under certain and uniform circumstances is so steady, that prior to the invention of clocks advantage was taken of it to regulate and indicate the divisions of time. The contrivances thus used were called *clepsydræ*. The most simple arrangement was where water flowed out of a vessel properly graduated. But as we have just shewn that the rate of flow would not be uniform, running out faster when the vessel was full, it became necessary to adopt some contrivance to compensate for this irregularity. The most commonly used arrangement for this purpose was either to employ a vessel smaller at the bottom end, and this divided into a certain number of equal parts, or to use a vessel of the same diameter throughout, the height being divided into a number of unequal parts, the least division being nearest the bottom. These plans were difficult to manage. We here give a drawing of a most ingenious plan by which the water-clock is self-regulating, the design of Mr. Partington; by this contrivance equal quantities of water are discharged in equal spaces of time. It will be perceived that the syphon plays an important part in the contrivance; it forms a good example of the adaptation of purely philosophical principles to practical purposes. The cylindrical tube *a a* holds the water, which serves as the measuring medium. A cork float *c* moves up and down

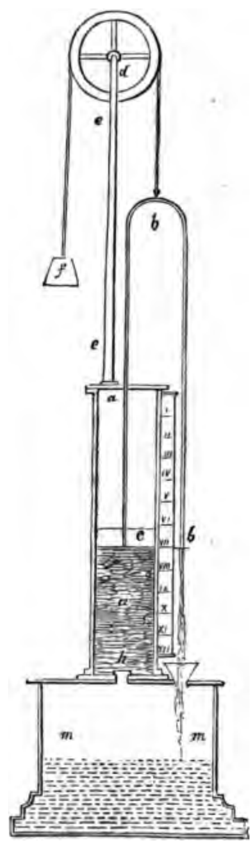


fig. 90.

in *a a* like a piston; the leg of a syphon *b b* passes through this float, and is suspended by a slight cord over the pulley *d*, supported by the standard *e e;* the weight of the float or syphon is nearly counterbalanced by the weight *f*. A pointer *b* is fixed near the delivering end of the syphon; this marks out the divisions of time placed at the side of the instrument. It is obvious that as the float by which the syphon is supported is always immersed to the same depth in the water, the outer leg will always remain in the same relative position to the surface of the water in the tube; thus the pressure being always the same, the flow of water will be uniform. As the water flows out of the cylinder by the syphon, the float and syphon fall, and the pointer consequently indicates the hour "as time flies by." The water discharged from the syphon falls into the box *m m;* and when required to be replaced in the tube the instrument is inverted, the water flowing into the cylinder through the valve *h*, which opens inwards, allowing the ingress of water, but preventing it from leaving the cylinder.

With that wonderful provision in the laws of nature for the adaptation of the earth as the dwelling-place of man, the mind is lost in gratitude when contemplating the power of friction opposed to the velocity of fluids, by which mighty rivers glide along at a quite moderate pace, and hence are nature's highways first resorted to by restless man.

Were the velocity of rivers not checked by friction, their force would be frightful; thus the Rhone, being 900 feet above the level of the sea, would pour into the ocean at its mouth with a velocity of 240 feet a second, or 164 miles an hour; and the Thames, with a fall of 100 feet, 54½ miles an hour. The friction increases as the stream proceeds, until the flow becomes limited and easy. But this depends on the quantity of descent in a given distance, and the surface of the bottom to the quantity of water. Now the torrents that rush down some of the Alpine steeps at the rate of eight miles an hour will carry with them stones four feet diameter; when the rate is two miles an hour, the size of the rolling stones is about three inches diameter; and when reduced to a quarter of a mile an hour, small sand only is moved along. Thus rapid rivers are stony, slow ones sandy or muddy. As a river is most rapid in the channel, and less so at the bottom and sides,—which is the cause of those sailing with the tide going into the middle of the stream, and those sailing against it keeping in shore,—the mean velocity is found in half the square root between the extreme difference of the velocity in the channel and at the bottom.

That the parts of a river near to the bottom or sides flow slower than the surface or middle, from being nearer solids from whence friction arises, may be thus illustrated. Suppose a long stick *a b*, loaded heavily with lead at the end *a*, so as to hang perpendicularly in still water, as shewn by the dotted lines. If the water in which this stick remained perpendicular when at

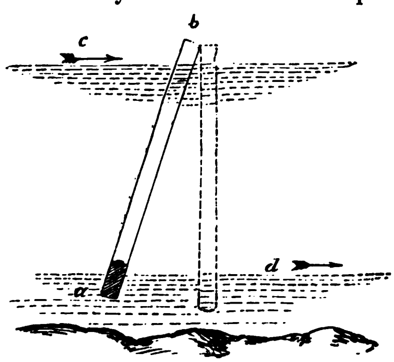


fig. 91.

rest in a pond, were allowed to flow out, or the stick removed to a stream running in the direction of the arrows *c* and *d*, the water near the bottom would flow so much slower than that at the top, that the upper end *b* of the loaded stick would be projected forward as in the diagram.

The rate at which a river flows may be estimated by placing against the stream a funnel having a bent tube; the higher the water stands in the tube above the level of the river, so is the velocity; as it will be the same as if issuing from a reservoir containing that depth of water, calculated on the same principle as falling bodies. Therefore it should be borne in mind that a falling body passes through 16 feet the first second, 32 feet the next, and so on; and that a hole an inch square, 16 feet below the top of the water, in one second will emit 32 feet of a stream, at four times the depth a double quantity in the same time, and gradually increase according to the rule stated. Some persons with a watch mark the time of a floating body passing; then by calculating the width and depth, making some allowance for friction, they easily ascertain the quantity of water and velocity of its passage.

The velocity of a stream or river varies according to circumstances. When the bottom has an inclination of about four inches per mile, then the rate at which the water flows onward will be found to be near to three miles an hour. A long straight river will be always found to be a rapid one; and many who have studied the subject can form a pretty near estimate of the rate of the current by merely glancing at a map where its course is laid down.

It is curious, when at the mouth of a river flowing into the ocean, to observe the meeting waters passing in different directions; thus the heavy sea-water will be flowing in while the light fresh water is heaved to the top and continues flowing out, so that there appears for miles out to sea a smooth muddy snake-like current spread over the vigorous heaving bosom of old Father Ocean.

If a ship be sailing at the rate of one mile an hour, in so doing it displaces so many particles of water; and if it sails two miles an hour it must displace twice as many particles, to do which will require twice the force to accomplish: but in doing this, not only is twice the force required to attain the speed, but as it has to displace the water with twice the velocity, the power has to be again doubled; thus, then, it is four; and therefore it is said that the square of the velocity of the moving body is required. In trebling the speed a force of nine will be necessary; and four times the speed will be obtained if a force of sixteen be applied to overcome the resistance. Then in steam navigation, if a 20-horse engine propels a vessel seven miles an hour, a 40-horse power will be required to impel it ten miles an hour, and so on, which causes very swift steamers to occupy a vast amount of space in carrying coal for their engines.

From calculating this resistance it is found that sailing vessels cannot attain a greater speed than fifteen miles an hour.

The Royal Yacht Club use very large sails in their handsome vessels, and by it gain a certain amount of speed; but the same proportion of sail applied to our merchantmen would not answer, as the additional speed would not compensate for the expense of the sails and the hands necessary to handle them, while the danger would be augmented. The Chinese, who

act on the principle of slow and sure, use smaller sails, proportionally to other naval powers, consequently their only loss is in a little speed.

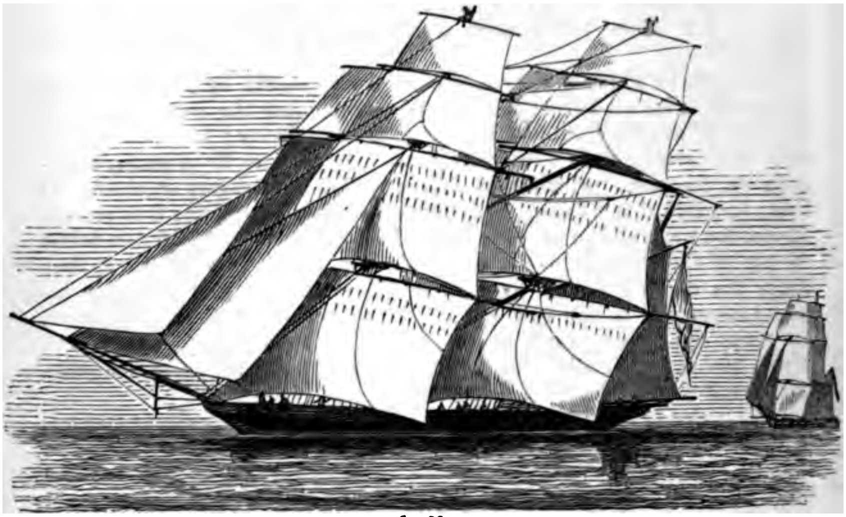


fig. 92.

"This law," says Dr. Arnott, "explains also why a ship glides through the water one or two miles an hour when there is very little wind, although with a strong breeze she would only sail at the rate of eight or ten miles. The hundredth part of that force of wind which drives her ten miles an hour will drive her one mile an hour; and the four-hundredth part will drive her half a mile. Thus, then, during a calm, a few men pulling in a boat can move a large ship at a sensible rate."

This action and reaction of a solid and a fluid is also felt when a ship is anchored in a stream, the strain upon it being estimated by the weight of a body of the fluid pressing upon it, as if it were a flat surface having a height according to its velocity. If the strain on a vessel in a stream having a speed of four miles an hour be equal to 16 cwt., then if the stream be eight miles an hour the strain will be 64 cwt. Thus, the same law exists as when a solid is moving in a fluid.

In the *Transactions of the Institution of Civil Engineers* it is mentioned by Mr. Macneil, that on the Paisley Canal two horses can easily drag a boat with ninety passengers ten miles an hour, but that it would kill them to drag it at a rate of six miles an hour, and that a speed of fifteen miles would be comparatively easy to that of six miles; that the usual laws of resistance on narrow and confined bodies of water only exist up to four or five miles an hour, and when a rate of nine, twelve, or fifteen miles are accomplished, the laws of resistance seem subverted or annihilated. To account for this, it is said the wave created by the boat raises it, but that the width of the canal and the size of the boat must have a relative proportion.

If a solid and a fluid meet obliquely, the effect on the surface of the solid is always perpendicular, but the impulse received by the force is proportional to the obliquity. This is exactly the same as explained in the

Resolution of Forces. Now, the vanes of a windmill directly face the wind, but from the thick arm the blades of the vanes are placed obliquely, gradually inclined from the plane of their rotation as they approach the axis; and therefore the action of the wind being perpendicular to these parts of the surfaces, the arms are driven onward, and, turning round, the axle communicates motion to the machinery. In some windmills, instead of covering the vanes with canvass, thin wood has been successfully employed. The Chinese often have wooden sails to their vessels, and the recent triumph of an American yacht with a straight stiff sail has demonstrated the superiority of this mode of rigging. The subject is now engaging the attention of nautical men, and we have no doubt that the time is not far distant when wooden sails will be universally adopted. They afford, likewise, considerable facility in their management compared to the sails now prevalent. If they were made similar to a Venetian-blind, they could with ease be furled on deck, and all the effects of reefing be accomplished by turning them edgeways to the wind. The quickness with which the required operations could be effected, the safety and comfort to the sailors, and the superior sailing qualities added to the vessel, all combine in urging onward those occupied in marine pursuits to overcome prejudices and adopt evident improvements. The exact pitch of the vanes of windmills has been long found by practical experience to be that of $12\frac{1}{2}°$ on the average near the centre of oscillation.

In 1802, Mr. Shorter applied a propeller like the sails of a windmill to the stern of a vessel in the Thames. Various attempts were afterwards made in this mode of propulsion, and in 1836 Mr. Smith took out a patent and built a vessel for the working of which was a screw 2 feet diameter, having a pitch 2 feet 5 inches. The next important vessel was the Archimedes, built by the Rennies, the screw of which had two threads opposite to each other, 5 feet 9 inches in diameter and 8 feet pitch. From this time the subject engaged the attention of scientific men, and the angle of the blades of the screw was owned to be one of the most important points to the perfecting of this system of navigation. We remember it being stated by Mr. Holmes, that, reasoning on theory alone, he was confident the common angle adopted in the formation of the vanes of windmills would be found most advantageous; that the resistance of a fluid was the purpose to be effected; and that no variation from the angle of the windmill was ever found beneficial, that practice had proved its correctness, and hence he judged it applicable to screw vessels. The numerous experiments that have taken place, costing enormous sums, seem now to have led to a decision in favour of the angle of the outer edges being $12\frac{1}{2}°$ with the plane of rotation—the angle of the vanes of a windmill.

We have often delighted in the exercise of sculling a boat, that is, by placing an oar out from the stern, and by giving the end in our hands a motion of a segment of a circle, driving the boat along; the surface of the oar that presses the water is turned obliquely backward, and the reaction of the water forces the boat onward. The tails of fish generally act in a similar manner, while the fins direct the motion.

A kite flown into the air is acted upon exactly the same as the vanes of a windmill, the belly-band being fastened to the lath, so that the surface of the aërial plaything may be oblique; while the wind acting upon it perpendicularly, it rises as if the cord was at a lower angle. Dr. Franklin

relates how delightful was the sensation of laying himself on his back, having hold of the string of a kite, and being drawn across a lake.

In the sledge expeditions in search of the noble Franklin in the Arctic regions in 1851, the progress of the sledges was greatly facilitated by kites when going before a stiff breeze; and, when the ground was level, by setting tarpaulin as sails, by which the exertions of two or three of the sailors were often saved on each sledge. When thus moving, they were likened to a fleet of Malay proas with their dark sail of mat, the snow seeming like foam on the sea. The bold and hardy men enjoyed this as fine sport, and ran along holding the slack ropes, forgetful of their severe trials. When land was not in sight, the sledges with their kites were steered like ships at sea.

Bishop Wilkins describes a land sailing-carriage somewhat in the form of a boat moving upon wheels, with two sails like those of a ship, and a contrivance to turn and steer it by having a rudder placed behind the hindmost wheels. It was stopped by letting down the sails or turning it from the wind. Similar inventions are seen in Holland: little vessels for one or two persons are placed on sledges and dragged onward by a sail. Some years ago a Mr. Slater traversed the Arabian deserts with dispatches to the East Indies, at times at a rate of twenty miles an hour, in a carriage having broad wheels and impelled by sails.

It is singular how science can reduce important matters to certain rules, and thus be of the greatest benefit to man. The philosopher in his study lays down a law, and the practical man by experience finds its truth. Now, when nations have established chains of intercourse by means of steam-vessels, how necessary to understand laws connected therewith, as just recited! On sea, four or six months have dwindled into twelve or fourteen days. On land and sea, in the communication of thought, four or six days have dwindled into four or six seconds; a merchant in London can in a few seconds communicate with his agent in Paris. Thus the mind of the world nearly beats with the mighty throb of one heart; mankind are feeling their own happiness to be that of their fellow-men—that all are but the instruments, the children of one God.

WATER-WHEELS.

Water flowing from ceaseless springs, and teeming from extensive watersheds, in its passage to the ocean seeks a course amid the valleys of the earth. The weight and momentum contained in this spontaneous gift of nature, man, from time immemorial, has endeavoured to turn to his own advantage; and although the steam-engine has stepped in, and rendered this power less important than heretofore, yet where water-power is abundant and constant, it offers that desideratum, economy, for various purposes of industry. Thus the principles of hydraulics, combined with laws of mechanics, have been studied to gain the utmost advantage of water-power in the construction of wheels to turn machinery.

The best mode of applying the power of water to wheels is found to be when the wheels are placed vertically, having, of course, their axis of rotation horizontal. The different wheels are designated according to the

part of the periphery or circumference on which the water acts,—*undershot*, *overshot*, *high* and *low breast* wheels. The *undershot* wheel is that in which a running stream operates against a series of flat boards placed around the outside of a wheel, by which it is driven round. The *overshot* wheel is that in which the water flows upon the wheel from a higher level than the wheel, and, falling into buckets or recesses, by its weight presses the wheel downwards, which, emptying in its descent, returns upwards light; and thus having a light and heavy side, motion is given to the wheel. A *breast* wheel is when the fall of water is lower than the diameter of the wheel; and when pouring on the wheel above its axis, it is called *high breast*; and when upon a lower part of the circumference, *low breast*. It must be obvious that these terms arise from the diameter of the wheel regulating whether the water falls above or below the axis. In these wheels both the momentum and weight of the water act in creating motion.

If water flowing from a mill-race be 3 feet broad and 2 feet deep, at a rate of 4 miles an hour, in an undershot wheel, multiply 3 by 2, that is the depth and width, this is equal to 6; then if the velocity be 4 miles an hour, that is 21,120 feet, this divided by 60 gives 352 feet per minute; then multiply 352 by 6, and the number of feet of water passing under the wheel per minute is 2112; but as the pressure of water is only equal to half the area of the float, the whole pressure per minute will be the half of 2112, or 1056 feet; and as a cubic foot of water weighs $62\frac{1}{2}$ lbs., its labouring force is 66,000 lbs. per minute, or 3,960,000 lbs. per hour. But in an overshot wheel there are great advantages, as the weight of the water acts on the wheel through a larger space; and in the breast-wheel there is the advantage of a perpendicular column of water.

Much ingenuity is exercised in the form and position of the buckets to receive the water; also the angle at which the water should be laid on has been a matter of discussion. In this country it is thought to be best at $52\frac{1}{4}$ degrees from the summit; while the French consider 60 degrees, that is, 30 degrees above the horizontal plane passing through the axle of the wheel, as most productive of power.

Rennie increased the width and diminished the depth of the buckets of water-wheels; he also applied the descending shuttle by which the flow of water is regulated over the upper edge, so as to obtain the full benefit of the fall, instead of passing under the shuttle, whereby some of the fall was lost; and by augmenting the velocity of the periphery or circumference from 3 feet to 5 feet per second, realised nearly 75 per cent of the power.

WAVES.

Wind, heat, and the influence of the moon, contribute in producing these mighty phenomena of nature. When the falling or rising of the tide of a river is opposed by a strong wind, an agitation is perceived, by restless waves rising and falling. If we watch a pan of water boil, as the light heated portions rise, an ebullition is created, which tosses the water to and fro, arising from the colder portions sinking, and seeking an equal temperature.

The water that forms a wave does not move onwards; it is only the surface rising and falling, the same as if we spread a long carpet or piece

of cloth on the floor, and shake it from one end,—the mode practised in dramatic representations of the ocean's waves. The motion of the waters moving progressively onwards, on arriving at a beach they curl over, and the communicated force they contain expends itself by friction against the shore. A pebble cast into a still pond causes waves, from a hollow being first made which the particles of water rush to fill up, and spring higher than the surface; this communicated force spreads itself over the whole body, from one part being affected, until it dies in murmuring whispers on the shore. The average height of a wave is about 12 feet, added to which is the hollow of 12 feet, or as it is called "trough of the sea," giving an appearance of 24 feet in height. During some storms in the Atlantic, that brave seaman and scientific man, Dr. Scoresby, states he has measured waves 43 feet above the level of the hollow occupied by the ship, and that the average waves are 15 feet high; while the peaks of crossing or crests of breaking seas would shoot up 10 or 15 feet higher. From crest to crest he estimates the mean distance at about 559 feet; the rate at which they travel, about 790 feet in sixteen seconds of time; and the breadth of the waves 220 feet.

Thus does science measure and mark nature in her calmest and stormiest moods. It will be seen from what we have stated, that when a vessel is made of an extraordinary length, its stem and stern will reach from wave to wave, and the midships be left unsupported by the sea, which must consequently endanger the safety of the vessel, being then apt to break its back, as nautical men term such accidents. The extraordinary timber vessels sent from America, as a mode more for the conveyance of the material than a cargo, were in such danger from accidents of this nature, that future trials were judiciously abandoned. The machinery of large steam-vessels rests on bridges of iron that span the vessel's length, thus giving strength to the midships.

Voyagers to Madras tell us of the vast waves continually breaking on the coast, which create a dangerous surf, extending some distance from the shore. As there are no harbours, the mails, and sometimes passengers, have to be landed in little rude vessels, called catamarans, that are driven through the surf; the boatmen are often washed off them, but being so accustomed to their management, and so practised in swimming, they regain their places, and preserve their cargo, with wonderful skill. A small river runs from the shore into the sea; and many an attempt has been made by the engineers visiting this important presidency, to render this available for the purposes of a harbour, but as yet fruitlessly. Captain Chisholm having observed a balk of teak wood, that had been driven by the force of the ocean into the shore, withstand the raging of the surf for some years, contrived a pier of timber to extend beyond the broken water, by which passengers and goods might at all times be landed. He exhibited a model of his plan in the Great Exhibition, which received the approbation of many engineers.

When the ocean tide meets the rapid stream of a powerful river, the former, being the stronger, rises up like a wall, and rushes with irresistible destruction along the coast. This is named the *bore*, and the injury to shipping and the coast is often of the most painful nature; it is most common near the mouths of the Ganges, and its effects are felt to a considerable distance. It arises from the two sea-waves produced by the

moon rolling in to shore. The effects of these are too well known on the Lancashire coast, where the traveller, not being careful enough as to the period of the returning tide, when journeying over the sands, finds it rush in with such rapidity, that unless he have a very fleet horse, be becomes a victim to his own neglect. Distressing accidents are continually occurring, even with a knowledge of the phenomenon, to the inhabitants of the district, from a thoughtlessness that seems inexplicable.

Fulton, the introducer of steam navigation in America, contrived a boat to sail under water, beyond the influence of the waves and storms; he thought by this method to destroy fleets at sea, and by thus rendering warfare a more destructive game than it really is, that other more peaceful modes would be adopted to adjust the quarrels of nations. Napoleon, though he saw it successful in an experiment, would not become its patron; and on a trial on behalf of the British government failing, the idea was abandoned. Nevertheless, the fact was established; and the only surprise is, that it has not been called into operation in short sea trips, to avoid the, to some, painful effects of sea-sickness. It may now more likely be attempted, since the discovery of an ingenious method by a Frenchman of reproducing the oxygen and destroying the carbonic acid in confined spaces, by which persons may both breathe and have a brilliant light in a vessel at the bottom of the ocean; or by the more recent adoption of compressed air for the purpose.

METHODS OF RAISING WATER.

We have already described and illustrated the mechanism and uses of pumps, but there are other ingenious methods, most especially those developed in the progress of scientific knowledge, that merit attention.

The most pristine mode of which we have any knowledge is that at present employed by the market-gardeners around London. It consists

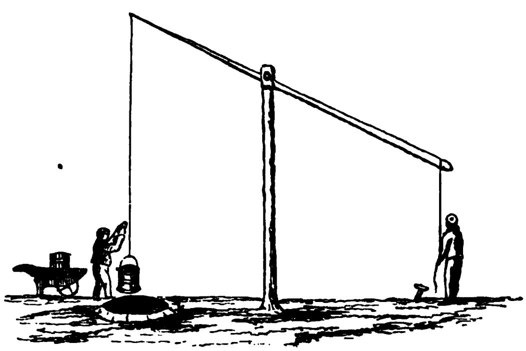


fig. 93.

of a long pole placed horizontally and balanced on an axle at the top of another long pole, or an adjacent stem of a tree, standing upright. The bucket, suspended over the well from a rope attached to one end of the horizontal pole, being dropped to the bottom and filled, in the action of which the end of the pole where the bucket is fixed sinks down and the other end rises, a man having hold of a short rope fastened to the part of the

pole now elevated, pulls it down, and the bucket rises from the well. This is a speedy method in comparison to the winch and axle, and answers excellently where the water is at no great depth.

The commonest mode of raising water from wells is that of coiling a rope by means of a winch or handle round an axle. The power required to lift the water is as the circumference of the axle to the circumference of the circle described in turning the handle. If the latter be twelve times the size of the former, then one pound at the handle will raise twelve pounds at the axle; therefore the less the axle, and the longer the handle, the easier is the work. Those who have tried this mechanical operation are aware, that if the well be deep the rope or chain has to coil again and again over the axle, and as the bucket approaches the top the work becomes harder and more strength has to be applied. This arises from the rope or chain increasing the size of the axle, and lessening the difference of the circumference of the circle of the handle in proportion to the axle.

How many reminiscences does the village well conjure up! the first fear in the education of the infant mind that the anxious loving mother endeavours to instil, though luckily in this instance eradicated by association with the object of dread; the test of strength in growing boyhood; the scene of rustic gallantry in budding manhood; and, alas, too frequently the painful toil of age; a beautiful impressive episode in Scripture, and a favourite spot for the theme of poets.

The accompanying diagram, fig. 94, shews a method of raising water in a somewhat similar manner to that of dredging up the mud and gravel at the bottom of rivers. A series of buckets *c c c c* are attached to a rope or chain which passes round two pulleys, or rather wheels, *a* and *b*, the lowest being sunk in the water that is to be raised. On turning a

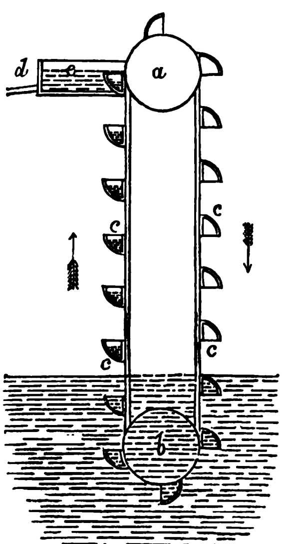


fig. 94.

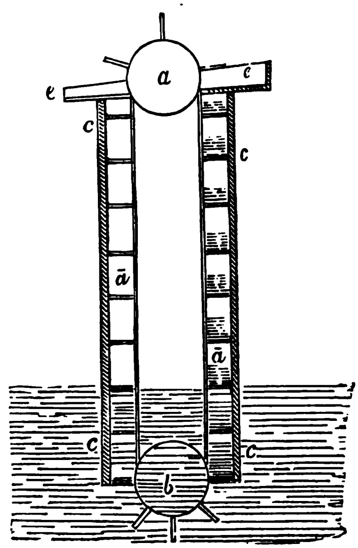


fig. 95.

handle fixed in the wheel *a*, the buckets rise on one side, and descend on the other in the direction of the arrows. The buckets that are raised up are full of water, and on arriving at the wheel *a*, in turning round, it is turned out into the trough *e*, and led away by the pipe *d*. This is called the "Bucket Machine."

The plan we have just described is improved upon, fig. 95, by having flat boards attached to the rope or chain instead of buckets. Passing over the wheels *a*, *b*, these are made closely fitting to a long tube or box $\bar{a}\ \bar{a}$; on the boards rising from the wheel *b*, they carry the water above them in the manner of a piston of a pump with a closed valve; and on reaching the trough *e e* the water flows in, having borne more upwards than could have been done by a proportionally sized machine with buckets. They are found to answer well in ships, and are called chain-pumps.

An extremely simple mode of raising water in opposition to its gravity has been for some time exhibited at the Royal Polytechnic Institution of London. A rough hair flat rope *f f* passes over two wheels *a*, *e*, when by the friction created by rapidly turning the handle *c*, a quantity of water is raised to the trough *b b*, from whence it is discharged by the spout *d*. The ascending rope passes through a wide aperture at the top, but on the opposite side is squeezed through a small tube, by which the water is retained. Instead of the handle, at the Institution a band is affixed, which is moved by a portion of the steam-power employed in giving motion to the machinery in the building. These are found to answer when the height the water has to be raised does not exceed ten feet.

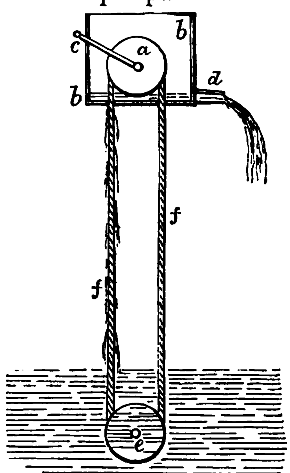


fig. 96.

The fens of Lincolnshire are considerably below the level of the sea, and are known to be saturated with water; many are the contrivances to drain the land, so that it may be rendered subservient to the purposes of agriculture. The most successful method is that of water-wheels. One of

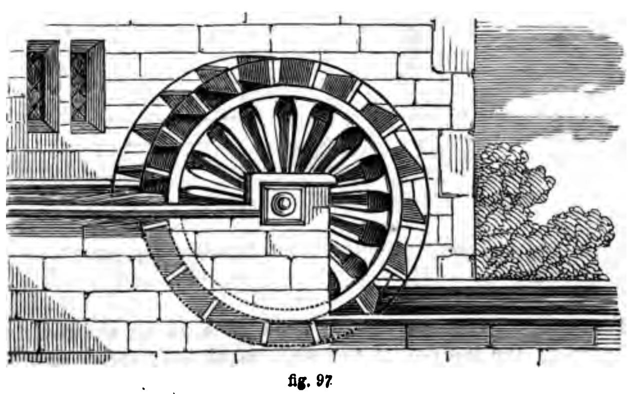


fig. 97

these being placed in the water, and having floats or buckets around its circumference, not radiating from the centre, but as tangents in a small circle set in motion by one of Boulton and Watts' engines, can raise a large body of water four feet in height; at some distance on this higher elevation a similar wheel is placed, and thus throughout the district the water is gradually raised four feet at each wheel: the effect of this system has been so extraordinary, that the land in the country of the fens is now found to be eight inches lower than it was twenty-four years ago.

An ingenious man, living on the banks of a river where a bridge was much needed, requiring water to irrigate his land, hit upon a plan by which both a public and private benefit was conferred. He built a bridge that moved on an axis in the centre, and in two parts, that is, divided from end to end along the centre of the roadway; each part was so balanced, that when one end was down the other was raised up a few feet; when a traveller came to either end of the bridge, he was sure to find one of the sides on a level with the road and the other raised up; of course he walked or rode on to that which was on the level, and after passing the centre his weight brought the opposite end down, and raised up the one on which he first stepped on to the bridge. Now, to the ends of the bridge were affixed pumps, and this action of rising and falling pumped up the water, which flowed into convenient reservoirs; thus, while the farmer benefited himself, he also benefited the public, and the pump-bridge was free of toll.

The visitors at the Great Exhibition of the Industry of All Nations, held in London in 1851, were struck with astonishment at the wonderful operations of the centrifugal pumps there in action. Before giving the details of these powerful engines, it may be as well simply to explain the principle of centrifugal pumps. If we suppose *a a* to be the well from

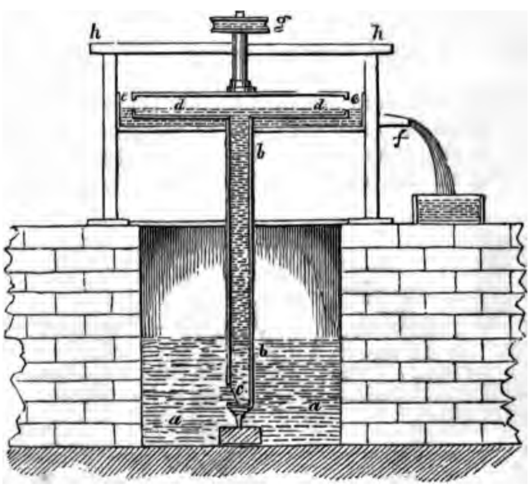


fig. 98.

which the supply is to be drawn, let a pipe *b b* be allowed to rotate on a centre at the bottom of the well, as at the "step" shewn in the drawing, and have motion communicated to it by a band passing over

the pulley g, and connected with a prime mover near the top of the vertical pipe bb; let two arms or pipes dd be placed communicating with the interior of $b\,b$, but at right angles; let these arms be open at the ends ee, and be above a trough supported by the frame $h\,h$. On filling the tube bb with water, which is prevented from passing out by the closing of the valve c at the aperture at the bottom of the pipe bb, and turning it by the pulley g, the arms $d\,d$ rapidly revolve, the centrifugal action will throw out the water by the ends $e\,e$ into the trough or box, and which will pass off by the pipe f; as the water is withdrawn from the top of the vertical tube by being passed through $e\,e$, the water is pressed through the valve c, and by this means the supply is continuous so long as motion is imparted to the tube; the valve c closing whenever the tube is stopped, prevents water passing out, and consequently does away with the necessity of filling the tube each time it is required to be worked.

fig. 99.

fig. 100

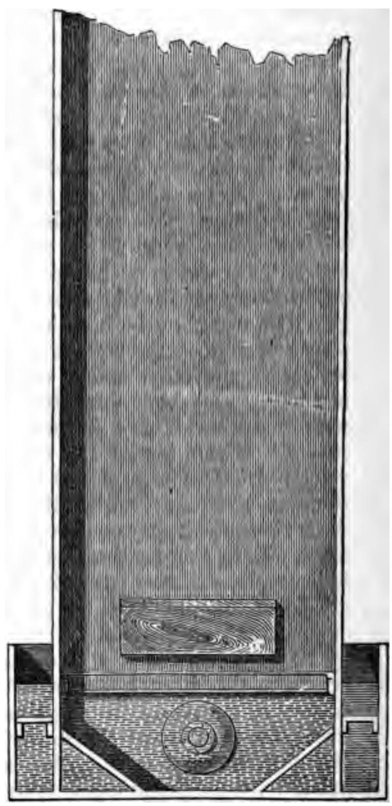


fig. 101

Amid the machinery at the Great Exhibition, towering above other objects by rising to the roof of the building, was a wooden pipe, in appearance like a chimney-shaft, from which, sometimes about half-way up, at other times near the top, rushed a broad sheet of water which engaged the attention of the visitors; this was Appold's Rotary or Centrifugal Pump.

The outward portion of this pump consisted of an upright shaft, 7 feet 6 inches broad, 1 foot wide, and about 22 feet high; fig. 100 is a vertical section, fig. 101 a front view. At the bottom of this was a tank of water. The first outlet for water was 1 foot high; the second 10 feet, with an area of 576 superficial inches; and the third 17 feet above the surface of the water, with an area of 1008 superficial inches: each outlet had valves; the middle one is seen open in fig. 100. A vertical pipe carried off the water to a lower tank.

Fig. 99 represents a hollow disc or cylinder, 12 inches diameter, with a round opening in the centre, 6 inches diameter; the rim measured 3 inches in width, which was open all around it; the other parts of this disc, excepting the centre, were enclosed. The water in the tank was drawn into, or received, at the sides of the circular opening of the disc of 6 inches diameter, and passing between the half-circular blades to the rim, was thrown into an iron case enclosing the disc; this case had an opening at the top of 63 superficial inches, through which the water was cast upwards.

Now we know if we turn a mop that has been dipped in water quickly round, the water is driven off to a distance proportionate to the velocity given in the trundling; and this it will be seen is the principle of the centrifugal pumps. We may also illustrate it by corn dropped in the middle of two stones when in revolution; the flour rushes off to the edges: hence, when water is thus propelled from a centre, if not allowed to fly off, by being confined in a case, wherever it can find an outlet, there will it go; if an upright tube, it rushes up that as a means of escape. The disc was placed upright at the bottom of the shaft, with a spindle passing through its centre, the other end of which projected at the back part, and had on it a wheel, 12 inches diameter; around the wheel was a band connected with steam machinery, having a $8\frac{1}{2}$ in. diameter cylinder, 2 feet 2 inch stroke. With a pressure of steam of 28lbs. on the square inch, giving a velocity to the piston of 250 feet per minute, the disc made 800 revolutions in a minute; which, if we multiply by the circumference, that is, three times and nearly one-seventh of the diameter, or, for even figures' sake, say 3 feet $1\frac{3}{4}$ inches, the velocity of the rim would be equal to 2516 feet 8 inches in a minute (truly 2512 feet). If we desired to know the superficial area thus produced for the outlet, the way is, to multiply the number of feet, 2512, by the width of the disc, 3 inches, that is, 7536; divide this by 12, to reduce to feet, and the result is 628 per minute. Now let us return to the disc; it was stated to be 12 inches diameter and 3 inches deep. A cylinder 1 foot high and 1 foot diameter contains 1357 and a fraction cubic inches; this must therefore be divided by four, as the disc is only the fourth of a foot deep, and the result will be a little over 338 inches; then a gallon contains over 277 cubic inches; hence we find that the disc will hold one gallon and nearly a quarter. Well, then, if the disc throws this quantity of water from it 800 times a minute, it delivers in that space of time 1000 gallons.

We have given these details more to shew the manner generally of making calculations, than in reference to the full capabilities of this particular pump, for there may be peculiar circumstances that we have overlooked important to its powers; indeed, there must be, as the inventor states that its delivery with these revolutions is equal to 1800 gallons per minute.

Mr. Appold states :—" From the results of various experiments, it has been found that the loss of power would not be more than thirty per cent. The centrifugal force is not so much in the large diameter, on account of the water moving more in a straight line; but that is compensated for by the force being applied to a greater depth of water, being 5 feet in the 20-feet, and only 3 inches in the 1-foot. 159 revolutions with the 1-foot will raise the water 1 foot higher, without discharging any; 318 revolutions, 4 feet; 636 revolutions, 16 feet; and 1272 revolutions, 64 feet high. The highest elevation to which the water has been raised with the 1-foot pump is 67 feet 8 inches, with 1322 revolutions per minute; being less than the calculated height, which may be accounted for by leakage with the extra strain.

" While the 1-foot pump is raising 8 tons of water 5 feet 6 inches per minute, there is no greater strain on any part of the pump than 160 lbs. on the 6-inch drum, which is equal to a leverage of 3 inches. It will pass almost any thing that is small enough to go through, there being no valves. A quantity of walnuts (about half a gallon) were thrown into the 1-foot pump all at once, when it was at full speed, and they passed through without breaking one."

A modification of the foregoing principle was exhibited in the same noble palace, containing the triumphs of man's ingenuity, which merits attention, from the simplicity of construction, portability, and neatness of design: it was by Mr. Clune. It might be either placed on a bracket attached to a wall, or be fixed on the top of a pedestal or column. The cylinder was placed horizontally, its axis projecting through the front of the case to a handle by which motion was communicated to it. The cylinder, having a flange at the bottom, was secured by means of bolts to the top flange of the supply-pipe, at the top of which pipe was the clack-valve in a curved chamber at the bottom of the cylinder, which led into the external channel, passing half round the cylinder, and terminating in a port at top. Behind this port was a vertical slide or diaphragm, which acted as a stop, and slid up and down in a groove, and was enclosed in a case above the cylinder, its lower edge being faced with leather, caoutchouc, or other suitable substances. For the greater part of the revolution of the horizontal shaft of the pump, the stop rested upon a cylindrical boss surrounding the shaft, which passed through one side of the cylinder by means of a stuffing-box, its opposite end resting on a fixed bearing on the other side of the cylinder. The boss was cast with an eccentric or spiral cam, the outer end of which worked in contact with the interior surface of the cylinder, whereas its sides were in contact with the ends of the cylinder. In front of the vertical slide was the delivery-port, with its valve opening out at the top of the cylinder, having a discharge pipe for the water or other fluid to be pumped up. At each revolution of the cam, which caused the stop or diaphragm to fall, a vacuum was formed behind it, after passing the inlet-port already described; and thus a body of water was at once

elevated to the cylinder through the lower valve, at the same time the water already in the cylinder in front of the eccentric was driven out through the upper clack-valve. The action of the gradually curved cam effected a smooth and easy action on the diaphragm, and a regular discharge of the fluid was secured by the rapid rotation of the cam.

There are other methods of raising water, which, more for their ingenuity than utility, we may notice here. One is named the "Horn drum:" *c c c* are arms bent in the manner that gives the appellation to the machine; these form scoops, and radiate from a hollow axle *a*. When the wheel is set in motion, the scoops, dipping into the water *b b*, raise some up, which, as the wheel rotates, falls towards the hollow axle, and, there being holes in it, passes to the middle, from whence it flows into the trough *d d*, and is then conveyed away as required. It is to be seen in operation on the banks of the mighty Nile, and is strangely illustrative of the mutation of nations, shewing that a people once the source of civilisation and science, are now outstripped by the energy of nations merely rising into existence; and makes us more highly prize that divine teaching that does not curb, but developes the mental faculties of man.

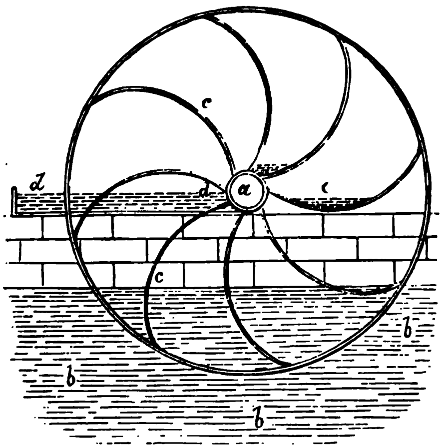


fig. 102.

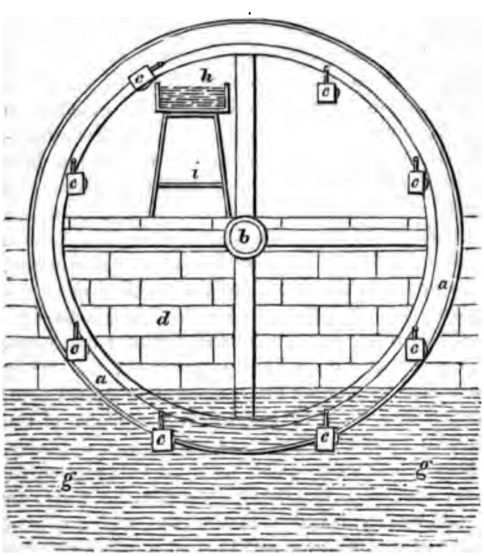


fig. 103.

The Persian wheel is a modification of the preceding one. It is used in running streams, and has floats on one side, similar to those of the paddles of a steam-vessel, by which motion is given to the wheel. On the wheel *a a* are suspended a number of buckets *c c c*, by means of strong pins; on the wheel turning round, these descend into the water *g g*, and become filled; as they rise, from swinging freely on the pins, their weight keeps them in an upright position. On reaching the

trough *h*, a spring on the side of the bucket goes against the edge, and causes the bucket to empty itself into the trough, after which it falls into its former position, and descends empty, to be again refilled. This is an improvement on the horn wheel, as the water is raised nearly to the top of the wheel, instead of only to the centre.

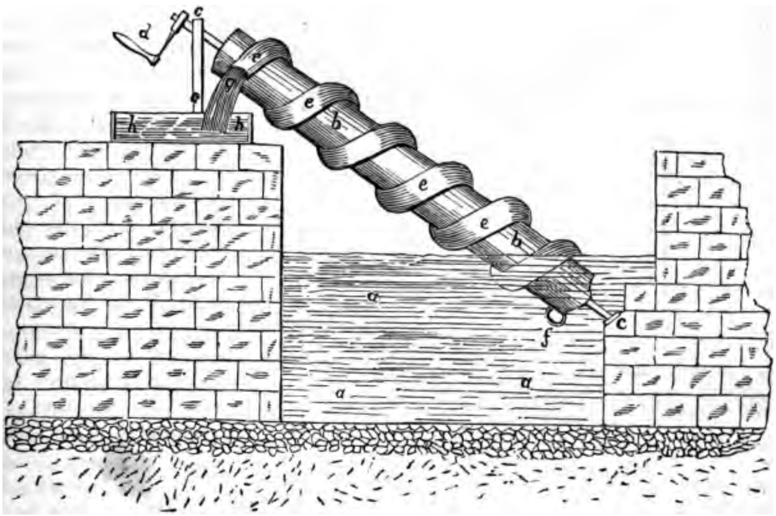


fig. 104.

There is another ancient method, even to this day found serviceable in particular cases, which, from its name, would lead us to date it as far back as the famous philosopher Archimedes, as it is called his screw. Round a cylinder *b b* a pipe *e e* is wound in a spiral manner. The pipe *b b* is placed in an inclined position, and an axle at each end works in bearings *c c;* the whole is turned by the handle *d*. The lower end *f* of the pipe *e e* dips into the water *a a*. On commencing to turn the cylinder *b b*, the water enters at *f;* but as the cylinder is turned, the orifice is raised, and the water in it consequently seeks the lowest position in the pipe; but another portion of water is entering, and a different portion of the pipe is occupying the lowest position. By continuing the motion of the cylinder, the water gradually progresses up the pipe, as up an inclined plane, till it reaches the highest position, when it is discharged into the trough *h h* through the orifice *g*.

Suppose water to be running from the lower orifice of a pipe placed vertically, and to be suddenly stopped by the instant insertion of a plug or other contrivance, a certain shock at the lower end of the pipe will be felt; and if the height of the pipe be great enough, the pipe in all likelihood will be burst. The reason of this shock being sustained in this manner is, that the downward motion of the water being suddenly stopped, and the momentum or force of the column of liquid being very great, the plug is struck with as much violence as if a solid bar of iron, of the same height and diameter, were falling at the same velocity on the plug; this

momentum of the water, acting on any body placed so as to arrest a quick flowing stream, is exemplified in the household water-pipe. If water is allowed to flow through a pipe leading from a cistern for some time, and then suddenly stopped by turning the stop-cock, a shock is sustained, sufficient in some instances to burst the lower part of the pipe. This pressure of an arrested flow of water has been made available for the purpose of raising water from a low to a high level; the contrivance by which this is effected is known as the "water-ram." It was invented by the celebrated Montgolfier, though the principle had been previously explained and exemplified in this country by Professor Millington. Suppose that a spring of water *a*, or a small stream placed at a little distance above the ordinary level of the ground *b*, as on the face of a knoll or small hill *c c*, run to waste through a channel leading to and passing off by the level ground beneath it. The water is confined in the first place to a pipe *b b*, instead of the open channel. This pipe communicates at the lower level *b′* with a horizontal pipe or chamber *e*, at the end of which is placed a valve; this valve, when drawn upwards, effectually closes the aperture through which the water escapes when the valve is down. The valve *e* is made so heavy, or weighted by small weights, that the stream has to run some time to acquire sufficient force or momentum to shut it. As soon as the valve is closed by the force of the descending water, the water passes up the tube *f*, in which there is a valve opening upwards; the water in the main pipe, in consequence of the quantity passing into the chamber *d*, becomes stagnant, and allows the valve to fall, by which a portion of the water from the stream escapes. As soon as the water acquires sufficient momentum from flowing through the valve-aperture, it shuts the valve, and a portion of the water is sent up the pipe *f*, and into the round air-vessel, from which it is sent in a continuous stream, and is prevented returning by means of a valve. Thus, if we suppose the stream in fig. 105 to be situated on the face of a hill or cliff, beneath a dwelling-house, a portion of the water could be sent up for household purposes by the pipe *f*. In fig. 106 we give an illustration of the improved form of water-ram now fitted up, in numerous instances by an hydraulic engineer, for the supply of water to houses, &c. situated as above. *a a* is the pipe leading from the source of supply to the escape-valve, opening and shutting at intervals, as described; *c* the passage to the valve *c′*, which opens inwards, the play of which is regulated by means of the screw, as in the diagram; *d* the pipe leading to the equalising air-vessel *e e*, from which the water passes up to the place of delivery by the pipe *f f*. As the water in the air-vessel is found in process of time to absorb the air contained in the vessel, the working of

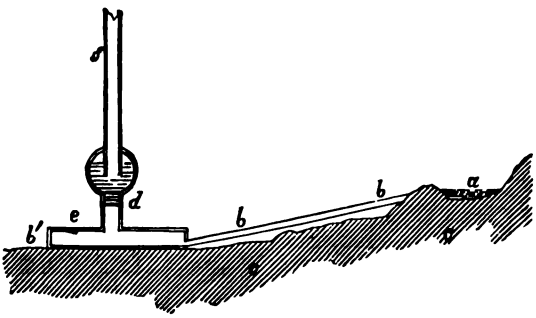


fig. 105.

the apparatus is prevented by the want of the elasticity necessary; this difficulty is obviated by applying to the air-vessel a contrivance called "a snifting valve," which admits a certain quantity of air at every stroke.

Before leaving this subject, we would notice that if a stream of water 2 inches wide were allowed for one second to flow down a pipe 30 feet long, having a slope of 6 feet, upon the forward pressure being arrested by a stop-cock, the momentum it would have acquired would drive half a pint of water up a pipe 40 feet high. This operation of closing the tap or valve every second, on the above scale, would raise 3 gallons 6 pints in one minute. A knowledge of this principle led an ingenious gentleman, Mr. Armstrong, to erect and work cranes at Newcastle-upon-Tyne by the pressure of the water in the common pipes that supplied the houses of the town. The machinery is below the surface of the street, therefore both out of the way and hidden from sight or accidents. There is a dial with handles or indicators communicating with valves, to regulate the pressure of the water below, by which the raising, lowering, or stopping of the machine is managed with the greatest facility. The simplicity, power, and cheapness of these hydraulic cranes, have met with general approbation.

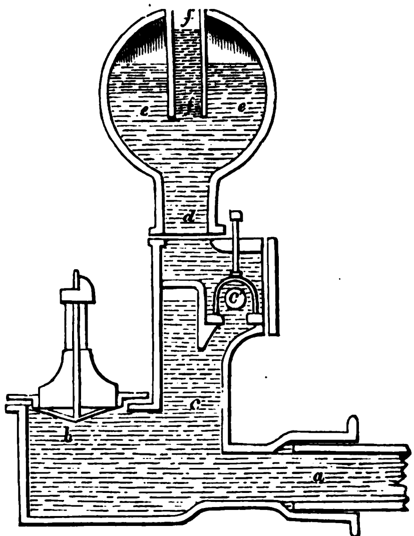


fig. 106.

ON SOME PORTIONS OF THE ANIMAL ECONOMY.

In a previous chapter we have given some details of the framework of the human body, and of the stays, ropes, or muscles by which it is held together, and acts with force or strength. There are also parts destined to perform hydrostatic and pneumatic operations, having pipes, valves, capillary tubes, and other wonderful arrangements for carrying on the vital principles that animate the human body, to which a few pages may be usefully and appropriately devoted.

We have said the teeth cut and grind the food by a power derived from the nerves; the muscles move the jaws, which become powerful levers; the tongue then moves the food about, and places it under the grinding teeth until it is all sufficiently reduced in size, and the lips prevent its falling out. While the muscles are acting on the jaws, they also compress glands situated between the ear and lower jaw-bone, and underneath the tongue; from these are ducts that lead to the middle of the cheek near to the ear, and the others open at each side of the membrane that ties the

tongue down to the inside of the lower jaw; from these a watery fluid exudes called saliva, that softens and mixes with the food, that it may the more easily glide down the throat. This is aided by smaller granular bodies, from which flows a mucous fluid, combining and adding to the slippery nature of the masticated food. The tongue moving upward and backward, rolls the aliment into that part we see on looking at the back part of an open mouth, which is named the pharynx; here are a number of muscular fibres, that, by contracting, force the food towards the stomach. The pharynx is, however, deserving of further notice. On looking upward are seen two large openings that lead to the nostrils. Between these and the entrance from the mouth is the part called the soft palate, which is a kind of fleshy movable curtain; in the middle is a pointed little lump, which projects outward, named the uvula. In this part are the bodies of a glandular nature, whose office it is to secrete a fluid that smears the part, to facilitate the easy passage of the pasty mass of aliment; these are the tonsils. The larynx, or commencement of the windpipe, or trachea, opens into the pharynx just at the root of the tongue; this part is termed the glottis, in front of which is a cartilaginous valve, standing perpendicularly, designated the epiglottis. Every one knows the great sensibility of the membrane of the windpipe, and that if the slightest morsel of food or other matter touches it, from its irritable nature a convulsive fit of coughing ensues; and that the folly of laughing or talking when eating meets with a painful punishment for the indiscretion. Yet every particle of food has to pass over the glottis, and this leads us to the mechanism of the art of eating. When we perform the act of swallowing, the tongue moves backward, by which action the windpipe is raised upwards, and the epiglottis descends, which effectually covers the opening; while the food having reached the pharynx, it presses upon it, and thus keeps it still more securely closed. The aliment having slid past, the tongue returns to its former position; the windpipe is drawn down, the epiglottis is again erect, and there is a free open passage for the breath. This beautiful simple mechanism acts from the motion of the parts themselves, independent of the will of the person or animal. But during this time the movable curtain has been assisting, for it closed over the nasal openings, so that nothing should pass in that direction; and were any thing rejected by the stomach, it is thrown, in such painful circumstances, with force against that part, and would thus find an exit, but it then closes, and little can force a passage, from the elevation of the soft palate over the openings.

The windpipe is divided into three parts, called the larynx, the trachea, and the bronchi. The larynx, we have said, opens at the root of the tongue, and is the upper part of the trachea. Five pieces of cartilage are employed to compose this important piece of mechanism; the largest, named thyroid, consists of two irregular quadrangular pieces that unite at an obtuse angle in front, and project at the fore-part of the neck. This projection, which is strongly developed in men, the vulgar believe or say originated in the moment of hesitation of our first progenitor before swallowing the forbidden fruit which, in an evil moment, he had been induced to take, and was to lead to sin; hence it is called the *pomum Adami*, or Adam's apple. Several ligaments are attached to the cartilages, and between two of them, the vocal chords, leaving a chink or cleft for the passage of the air, through which is formed that great gift to man—voice. The

lining of the larynx is softened by a plentiful supply of mucus, which defends it from the coldness or heat of the external air. It is perfectly pliant to the movements of the neck. One of the cartilages, cricoid, is of the shape of a ring having a seal in it, the broad part being placed behind; to this are connected two pyramidical portions of cartilage, arytenoid, whose movements alter the size of the commencement of the glottis, and slacken or brace up the vocal chords; and thus are given the beautiful modulations and tones of that most divine harmony of which the human voice is capable.

The trachea extends to the bronchi, and is a tube of from five to seven-eighths of an inch in diameter; it is in the middle of the fore-part of the neck, and before the gullet. If we take some hoops, cut away about the fourth part, then taper the ends, lay a thick part on the thin part of the other, and thus build them up, attaching them to each other by an elastic membrane, we form a pliant pipe, and have produced a resemblance to the trachea. It is very sensitive, and lubricated with mucus. The bronchi is the trachea divided into two separate tubes branching into the two lungs,—the right is the largest and the shortest; these divide into smaller and smaller branches, that they may ramify into all the air-cells; and it is the inflammation of these fine tubes, or their disorganisation, that creates the distressing and often fatal malady called bronchitis.

We must now return to the food which had got so far on its journey as the muscular tube, called the gullet or æsophagus, from whence it passes onward to the stomach; this is a muscular membranous bag somewhat in the shape of what we see forming bagpipes, larger at the left, and decreasing in size to the right, curved or arched at its exterior, with two openings, and capable of holding, from the habits of the proprietor, from five to eleven pints. The inside is as delicate, and bears a resemblance in structure to, velvet.

The effect of the folly and impropriety of indulging too much in any food that is gratifying to the taste may here be noted. The abdomen is rendered tense and projects; and by its enlargement the part called the diaphragm or midriff, which divides what is termed the superior from the inferior parts, or the cavity of the chest from the abdomen, is forced upward into the chest, which allowing less room for the action of the important functions there performed, the breathing becomes difficult and is hurried, thus rendering speech often what is popularly termed thick; by the fulness of the abdomen the blood is driven to other parts, and often ascends to the head, where, collecting in the arteries in too great an abundance, it produces that fatal and rapid malady, apoplexy. From these remarks it must be apparent that it is consistent with reason to rest, and not induce disease by exertion, when the stomach is full, exercise being sure to aid in the propulsion of blood to parts already overgorged.

On the food reaching the stomach, a liquid oozes out of the internal surface, which is called the gastric-juice. This juice will dissolve almost any substance, the casing of seeds forming an exception; it reduces the food into a mass named chyme, which next passes a contracted ring, the pylorus, or keeper of the gate, which had prevented its egress until the gastric-juice had performed its duty, and enters the smaller intestine, named the duodenum; and as it journeys on receives a mixture of bile

and pancreatic-juice from the liver and pancreas; the milky fluid known as chyle is now produced, and is absorbed by lacteals, or milk-pipes, which convey it to a vessel in the chest, where it is mingled with the blood and nourishes the body. The refuse passes along a long tube or canal about an inch or inch and a half in diameter, and after numerous turnings and windings is finally expelled from the body. The distance it travels is about that of six times the length of the body of the individual.

The long intestinal canal is smooth in its outer surface, to which there is a constant supply of a slippery fluid, whereby it glides about with perfect ease. The expulsion from thence takes place by the elasticity and muscularity of the coats, which, by successive contractions of its fibres from the higher to the lower parts, act by a gentle pressure around the tube, carrying onward the contents.

Dr. Arnott remarks—"The abdomen may be considered as a vessel full of liquid, on which there is a pressure in all directions, increasing with the depth (see Hydrostatics), and increased also by the action of the surrounding muscles which form the sides of the cavity.

"Straining, or strong action of the abdominal muscles, and therefore pressure on the abdominal contents, occurs with almost every bodily exertion; for the abdominal muscles are the antagonists of the great muscles on the back and about the spine, and must always come into play with them, to give firmness and rigidity to the trunk of the body. This may be seen remarkably in the actions of lifting, running, wrestling, &c. As the abdominal muscles cannot act in a continued way and strongly, unless the ribs, from which they arise, become nearly fixed, during exertion the ribs are supported by the intercostal muscles, and by the air in the chest, confined for a time by the closure of the air-passages in the throat; hence there is generally compression in the chest also when the abdomen is compressed, and the blood is squeezed towards the extremities from both cavities at once. It is important to remark here, that in what are called the strong actions of the chest, as coughing, sneezing, blowing, &c., the abdominal muscles are the great agents. By pulling down the ribs to which they are attached, they narrow the chest; and by pressing the abdominal contents, and thus raising up the diaphragm, they shorten the chest."

We have proceeded as far as the formation of food into a substance that goes to nourish that important fluid the blood, the circulation of which is a subject of interest. That portion of the scientific world pursuing the ennobling study of anatomy owes its progressive impulse to the grand discovery of the renowned Englishman Dr. Harvey, who announced the fact in 1628.

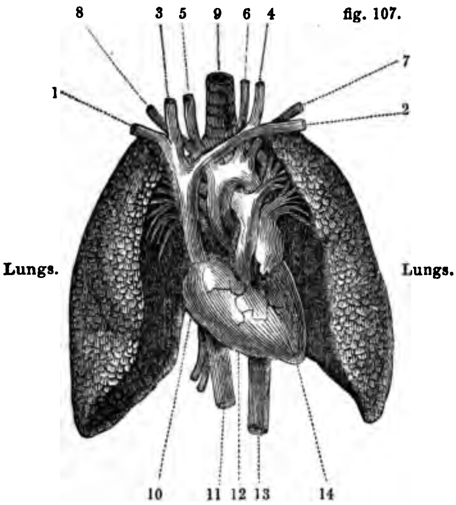
The arteries and veins are arborescent over the entire body; springing from a root at the heart, the thickly-placed branches and twigs of which ramify through every part.

The position of the lungs, heart, and principal vessels of the human body may be more easily comprehended from the following illustration.

Arising from the left chamber or ventricle of the heart is the great arterial tube called the aorta, which dividing and subdividing into smaller and smaller tubes, until the termination of some are lost in their very minuteness, they pervade the furthermost extremity of the living body, carrying in their canals the life-inspiring bright-red blood that gives warmth and replaces the waste going on in the system. When these services have been

accomplished the extreme distance is attained, and the vigour and ruddiness of the fluid becomes a deadened purple hue; then the vessels are reflected back, and form so many minute streams of veins which, joining into larger channels, ultimately reach the part from which they started, the

fig. 107.



1, 2. Subclavian arteries, giving off blood to the upper extremities.
3, 4. Jugular veins.
5, 6. Carotid arteries.
7, 8. Subclavian vein.
9. The trachea or windpipe.
10. Right auricle of heart.
11. Inferior vena cava, or large inferior vein.
12. Right ventricle of heart.
13. Aorta.
14. Left auricle of heart.

A representation of the Lungs, Heart, and principal vessels.

heart, there to undergo purification and addition: thus the arterial and venous trees become joined, but each performs a separate function; the one carries onward the fresh red stream, the other returns the exhausted, purple, thickened liquid.

Had not the blood been thus separated into little streams and drawn off on its passage into other channels, but gone straight down to the lowest extremity, we may imagine what a weight it would have felt at those parts from the amount of fluid outward pressure, which increases about half an ounce every square inch. After a meal the action of the heart is accelerated, and still more so during bodily exertion or mental excitement; it is slower during sleep. And it appears that the frequency of the pulse is in some degree regulated by the same causes; in the morning it is more frequent, and becomes gradually slower as the day advances, decreasing more rapidly towards the evening, and from fatigue. The standing and sitting position affect it in a similar manner; and food, like that of change of posture, more so in the morning than in the evening.

The heart lies towards the left side; the broad part towards the right and backwards, and the pointed part towards the left, forwards and downwards. The flat surface rests on the diaphragm, and therefore, as this part moves upwards and downwards in the act of breathing, raises and lowers the heart. The pointed part is opposite the cartilage of the fifth and sixth left rib; and in this part there is a portion of the left lung removed, as if to give ample room to the action of the heart. It is encased in a bag, in which is a fluid to give moisture and ease of motion. When taken from the body the heart weighs from ten to fifteen ounces, and is larger in proportion to the body in the young than the old subject, and

frequently smaller in tall and strong men, than in those of ordinary height and moderate muscular powers. The heart consists of two parts closely connected together, each of which has two cavities: an auricle, or membranous bag, placed at the mouth of the veins; and a ventricle, or strong muscular chamber, placed at the orifice of the artery. When the purple fluid returns, it is poured into the right auricle of the heart by three veins; the nutritious portions of the food are poured by absorbents and the thoracic duct into a large vein, and mix with the returned blood as it passes in an agitated state through the heart. This auricle, which derives its name from some supposed resemblance to a dog's ear, has a small fringed process, and its inside surface is smooth and polished, having some muscular fibres arranged so as to be compared to the teeth of a comb. Next, through a large round orifice, the blood enters the right anterior or pulmonary ventricle; and here it is prevented being driven back by a valve, divided into three pointed portions, with numerous tendinous strings, by which it acts. It may here be observed, that a ventricle is a strong muscular cavity with power to forcibly propel the blood by contraction, while the auricle is a mere supply-tank to fill the ventricle as it becomes empty. The blood passes next to the arterial orifice of the ventricle, where there are three valves of a half-moon shape to prevent any retrograde movement; and being now in the pulmonary artery, is emptied into the lungs, where it is brought into contact with the very fine and delicate bronchial capillary tubes; extracting from them the oxygen of the air, conveyed there in the act of breathing, it becomes vivified scarlet arterial blood. Four pulmonary veins, two of which belong to each lung, now pour the freshened blood into the large left or posterior auricle, which is at the upper or back part of the heart; here, again, is a valve likened to a bishop's mitre; and the blood is now fresh, red, and warm, ready to commence its tortuous journey, and give life and energy and food to the entire body. The left ventricle is thick and strong, like a solid mass of flesh, having to drive the blood up the aorta, which is guarded by three half-moon valves, and send it to the remotest parts. The aorta is the great tube from which all the arteries branch and receive their precious burden.

The lungs are a spongy substance, the vessels and thin membranes of which are chiefly formed into cells that would cover a surface equal to about thirty times that of an ordinary sized man's body. Into these the air we breathe being received, the oxygen is taken up by the blood, and the other parts rejected and returned. As the chest expands the air rushes in, and is expelled by its contraction. The lungs are divided into five parts or lobes, three lying on the right side of the chest and two on the left, and are enclosed in a bladder-like substance, named the pleura. The air rushes in among the minute and thin vessels containing the blood, and every part is penetrated by it—every atom—when a chemical change takes place, and the black impure blood becomes a bright scarlet.

The principal force provided for constantly moving the blood through its course, is that of the muscular substance of the heart, assisted by the elasticity of the walls of the arteries, the pressure of the muscles upon the veins, and the movements of the walls of the chest in respiration. If an upright tube were connected to an artery, there would usually be found a column of blood about eight feet above the level of the heart; and calcu-

lating this in the manner described under the chapter Hydrostatics, the pressure must be about four pounds per inch. The same experiment applied to the veins would result in a column only half a foot in height, and hence the pressure would be defined as a quarter of a pound per square inch.

The force with which the left ventricle of the heart contracts is about double that exerted by the contraction of the right. This difference in the amount of force exerted by the contraction of the two ventricles results from the walls of the left ventricle being about twice as thick as those of the right; and the difference is adapted to the greater degree of resistance which the left ventricle has to overcome, compared with that of the right; the former having to propel blood through every part of the body, the latter only through the lungs. Blood left in a vessel separates into distinct parts; but this violent action in the heart mixes them all up, and so sends them forth in a condition which the offices to be fulfilled render necessary; and it thus becomes the pendulum of life that first announces the commencement of the vital cycle, and its cessation, the end of which is death.

The aorta arises from the heart over the chest in an arched syphon-like manner, and then its scarlet contents are poured down, and the weight of the column of blood sends it through the capillaries to an equal height in a corresponding vein, as was explained in Hydrostatics, that fluids attain the same height in all communicating vessels. Not only does this law of gravity aid the circulation of the blood, but also the powers exerted to the extent of a column eight feet above the heart. When at the extremities the blood passes through the narrow orifices, and is forced up the venous tubes by the same power which is sufficient to raise it above the heart, as if a force-pump were raising water in this manner and filling a tube, having power not only to this extent but also to overcome friction, and sustain the column which is increased in weight in proportion to the depth.

When we draw in our breath the chest is expanded, and the muscular powers being then stretched, circumstances are rendered favourable for the passage of the blood from the veins to the heart; and on throwing the air out of the chest, the muscles contract and the diaphragm rises, by which the passage of the blood is resisted; but the recoil is arrested by the valves; as the force is only equal to a column of half a foot, this is easily overcome.

An artery, or holder of air, as the ancients denominated it, from finding it always empty upon dissection after death and thence supposed to be an air-tube, is circular in form, and consists of three strata of different substances called coats. The innermost is thin, strong, inelastic, and smooth; and if injured, the regular round form is lost to the tube. The middle coat is composed of a number of muscular circular fibres. The outward coat is a condensed cellular substance and very elastic: thus there is an elastic power with little muscular force; and if pressed, or too much stretched, it easily returns to its former condition. When a small artery is cut across, it contracts at the part, and therefore aids the preservation of the life-giving fluid; thus in bleeding to death the arteries contract to the decreased size of the stream. Sometimes, in dissec-

tion, a single fibre will contract as if it were a string tied round the mouth of the tube, and when tied by a thread the parts adjacent contract, firmly securing the orifice. The arteries contain about five pounds of blood, and their pulse is felt over the whole body nearly at the same instant.

On the passage of the blood through the capillaries, Dr. Arnott thus eloquently writes:—"We have seen that the heart keeps up a tension or pressure in the arteries of about four pounds on the square inch of their surface; and with this force, therefore, is propelling the blood into the capillaries. If these last were passive tubes, constantly open, such force would be sufficient to press the blood through them with a certain uniform velocity; but they are vessels of great and varying activity; it is among them that the nutrition of the different textures of the body takes place, as of muscle, bone, membrane, &c.; and that all the secretions from the blood are performed, as of bile, gastric juice, or saliva, &c.: and to perform such varied and often fluctuating offices, they require to be able to control in all ways the motion of the blood passing through them. The capillaries of the cheek, under the influence of shame, dilate instantly and admit more blood, producing what is called a blush; under the influence of anger or fear, they suddenly empty themselves, and the countenance becomes pallid—tears or saliva gush in a moment, and in a moment are again dried up; if a person having inflammation in one hand be blooded from corresponding veins in both arms at the same time, twice or thrice as much blood will flow from the diseased side as from the other. Similar changes occur in many other instances. Now the only mechanical action of vessels capable of causing these phenomena must occur in contractile or muscular coats; and with reference to such action it merits notice, that arterial branches have always more of the fibrous or contractile coat in proportion as they are smaller.

"A muscular capillary tube strong enough to shut itself in spite of the action of the heart, is also strong enough to propel the blood to the heart again through the veins, even if the resistance on that side were as great as the force on the other. For if we suppose the first circular fibre of the tube to close itself completely, it would, of course, be exerting the same repellent force on both sides, or as regarded both the artery and vein. If then the series of ring fibres forming the tube were to contract in succession towards the vein, as the fibres of the intestinal canal contract in propelling the food, it is evident that all the blood in the capillary would thereby be pressed into the vein towards the heart. If, after this, the capillary relaxed on the side of the artery so as to admit more blood, and again contracted towards the vein as before, it might produce a forward motion of the blood in the vein independently of the heart. We, of course, state this merely as a possibility, for the intimate nature of capillary action is not visible, and is not positively ascertained.

"It is capillary action which absorbs and moves the fluids of the classes of animals which have no heart. It must also be the power which moves the blood in warm-blooded monsters formed without hearts. There are cases of apparent death among human beings where the heart remains inactive for days, and yet a degree of circulation sufficient to preserve life is carried on by the capillaries. In further illustration of capillary action, we have the absorption of nourishment from the alimentary canal by the

lacteals ; and perhaps, to a certain extent, the circulation of the blood in the liver of animals. In this last case the blood collected by veins from the abdominal viscera, instead of going directly to the heart, is again distributed through the liver by the branches of the vena porta ; and is then again collected by ordinary veins, and carried to the heart. It thus moves through two sets of capillaries in passing from the arteries to the heart again.

"The action of the capillaries is the cause of that singular phenomenon which prevented the ancients from discovering the circulation of the blood, viz. the empty state of the arteries after death. All the muscular parts of an animal, including, therefore, the contractile coats of vessels, retain their life, or power of contracting, for a considerable time after respiration has ceased, as is seen in the recovery of persons apparently drowned or suffocated ; in the leaping of a heart taken from an animal just killed ; in the actions resembling life which can be produced, by the agency of galvanism, in a body recently dead ; and still more aptly for our purpose, in the total disappearance of a local inflammation after the death of a patient. Inflammation involves a gorging or over-distension of the capillaries ; and when the heart has ceased to press blood into them, the contractile force remaining in them, even under disease, and in a dead animal, is sufficient to squeeze the blood out of them, and often to remove all trace of the malady which had been fatal. In ordinary cases, the capillaries throughout the body remain alive and active for a considerable time after breathing has ceased, and they work like innumerable little pumps, emptying the arteries into the veins. As the red blood is their proper sustenance as well as stimulus, they work as long as there is any of it coming from the arteries behind them ; the capillaries of the lungs, however, soon cease to act, because, after breathing has ceased, they are filled with black blood, and are moreover compressed by the collapse of the chest, and all the blood accumulates behind them. The capillaries may continue to be filled from the arteries, either in consequence of their elasticity opening them with what is called a suction power, or of an absorbent power dependent on life, like that of the lacteals and of the absorbents all over the body, and, perhaps, of the vessels in the roots of vegetables. When death is produced by lightning, or by the poisons which destroy muscular irritability, and therefore capillary activity, the arteries after death are found to contain blood like the veins. In a living body, if an artery be tied, the part beyond the ligature is soon emptied into the veins, and becomes flat. The experiment has been made even upon the aorta itself.

"The empty state of the arteries after death is still ascribed by some teachers to the momentum with which the blood is supposed to be thrown out from the heart in its last contraction, sufficient, according to them, to squirt it fairly through the most distant capillaries ; a doctrine exemplifying the carelessness with which able men sometimes receive and repeat opinions, to which their attention has never been fully awakened. The effect supposed here would not follow, even if the dying action of the heart were the strongest possible ; while, in reality, it is in most cases so feeble, that the pulse for some time ceases to be perceptible at the extremities, and the diminished circulation lets them become cold. Other physiologists teach that an artery is capable of contracting directly upon its contents, so as to expel even the last drop ; but large arteries, when emptying, do not contract *roundly* like

an intestine; they become *flat*, like elastic tubes of leather sucked empty, and no contractile action of the vessel itself could bring its sides together in such a manner. If arteries emptied themselves by their own action, the pulmonary artery should be more certainly empty than the aorta, because it is shorter; yet it is always full, the chief reason being, as already stated, that the pulmonary capillaries cease to act after respiration has ceased, because the blood in them is the venous or dark blood, and therefore not stimulant."—*Elements of Physics*, vol. i.

Besides the downward flow of the blood, there is also the important upward one to the head. The head being a close bony cavity, is not susceptible of atmospheric pressure, but the veins and arteries that spread over it are kept full from that cause, of which we have spoken in a previous page; and though the quantity may vary in other parts of the body, it does not do so in the head, where the vessels are in a similar position to that of a syphon in action. When the flow of blood to the brain is interrupted by the cessation of the action of the heart in fainting, or the supply of fresh air to the lungs cut off, so that the blood rises to the head impure, as in suffocation, insensibility takes place, and if not speedily relieved, convulsion and death. The arteries of the brain not having to sustain the same outward pressure as in other parts of the body, are considerably weaker, while the veins are placed in grooves of the bone, and have a strong covering, so that they cannot collapse by any sudden tension of the arteries, as other veins would do, and thus are singularly adapted for the preservation of thought and life.

There are other parts subservient to the functions of the body, that are equally surprising in their adaptation to the purposes of their design, but do not come within the province of this work.

Man has been compared to a machine, but we consider inaptly so; for no machine is at all comparable to that frame sent forth in creation when God said, "Let us make man in our image, after our likeness," and He "created man."

Examine the head, where the union of spirit and body resides in the brain, and the mind emanates to guide the actions. Consider the organs of sense, the eye to see, the ear to hear, the nose to smell, the mouth to taste, and the skin to touch, while thus holding communion with the objects around.

For safety, by communicating sensation to the brain, and the will to the muscles, do we see the beautiful arrangement of the nerves.

Then there is the mechanism of the muscles and tendons, giving the power of locomotion to flee from danger or supply wants.

There is firmness, shape, protection, and strength to all the soft parts, from the bony skeleton throughout the entire body, having ligaments to bind them together and allow of motion, to the smooth slippery surfaces to prevent wear and afford easy movements.

The hollows are filled up with fleshy or fatty matter, and the whole is made compact and defended from injury by the covering of the skin.

That thoughts and feelings may be communicated, and the grand gift of social intercourse be enjoyed, there are the organs for the faculty of speech.

That this body may endure by being refreshed, renewed, and repaired, there is blood impelled by the heart and the arterial system; while the

veins bring back that which is not required, and with it the collected refuse matter; this is separated by glands and other organs straining it, and the useless superfluous parts being extracted, are passed away by excretory vessels.

The teeth reduce the bulk of the food procured by hands; and the stomach chemically changes it, by which fresh blood is created.

Man breathes and aids the purity of his blood, and supports the warmth of his body, but beyond its necessity for the continuance of life we know little.

If a body becomes injured, the wound heals or the bone reunites, a dead part is cast off, and other parts renewed.

The stomach announces its wants, and tells when sufficiently supplied. Thus, then, there are properties that leave far behind any machine ever contrived by man of internal powers of self-preservation, that palpably proclaim in their formation the wisdom and wonders of a divine Creator.

ACOUSTICS, OR SOUND.

Acoustics is a term derived from two Greek words signifying the science of hearing. It recals to the mind one of the most delightful senses enjoyed by man, embodying in it the power of language and the raptures of music.

When a bell is rung under an exhausted receiver of an air-pump, hardly any sound is audible. The same bell struck in the open air is distinctly heard, and if hit with the same force in a sunk diving-bell, where the air is compressed, it sounds with increased power; thus is shewn that the air is the medium through which sound is conveyed.

Place a wine-glass mouth downwards on a table, and tap it sharply with the finger-nail, the blow is merely heard; but raise it up and then hit it, and a musical sound rings on the ear, which will be increased by slinging it with a piece of string. This arises from the circumstance, that when held gently by the hand, the glass is free to vibrate in the air, and more so when slung from the cord; thus vibration is the cause of this sound. The agitation of the glass from the blow gives impulse to the air by which it is surrounded, in the same manner as water undulates in circles when a stone has been thrown on its peaceful surface; and these aërial waves coming in contact with the drum of the ear, the nervous membranes convey the impression of sound to the mind.

A meteor passing through the air has been known to create such an agitation from its velocity, as to shake the windows of a house with considerable violence.

Some sounds differ in intensity; and if one sound drowns another, it is said to be more intense, provided it be the same note; others differ in pitch, as the high and low notes of music; and others in character, as the tone of the same note sounded on two different instruments. So wonderfully delicate and acute is the organisation of the human ear, that man can hear and distinguish almost any number of different sounds at the same time.

A rapid motion given to certain objects, as those of the prongs of a tuning-fork, the strings of musical instruments, the coverings of drums or gongs, and other contrivances, produces sound; the agitation that ensues communicating itself to the surrounding air, a succession of vibrations ensues, which reaches the ear and is called sound; but the particles of air in contact with the ear must vibrate at least thirty times in a second before the impression of a musical note can be received.

The atmosphere around us, if moved in a body and with the same velocity, produces no sound; thus a high wind must be driven against some obstacle before the voice of the hurricane is heard, because that object vibrates. The booming of cannon, and the joyous peal or funereal note of a bell, is borne in agitated waves along the atmosphere, in whatever direction the wind may blow; but neither they nor the sound of a thousand brazen instruments produce the slightest degree of wind in any direction. Still when a powerful instrument is sounded near to a table on which glasses are placed, they will be observed to tremble, and even caused to fall to the ground; while in instances of great and sudden explosions, the air will be so agitated for a distance, that windows may be broken, and yet no sound heard. On the explosion of a powder-mill at Hounslow, the windows of houses at Greenwich were shaken, a distance of about twenty miles.

From man living in an aërial ocean, it is the general medium through which sound is conveyed to his senses, being in direct communication with the tympanum or drum of his ear; but other bodies, solid or fluid, having their particles of matter closer than air, and possessed of a moderate degree of elasticity, if placed between the exciting cause and the ear, form mediums for the conveyance of sound. The velocity of sound in air is 1125 feet per second. A bell rung under water has been distinctly heard at a distance of nine miles, which sped at the rate of 4708 feet per second. Thus it is found by accurate calculation, that sound travels more than four times quicker in water than in air. If a person scratch one end of a long piece of timber with a pin, and another person apply his ear to the other end, the noise can be distinctly heard by the person at the distant end, although not by him using the pin. The same applies to the ticking of a watch, that only a few feet distant with the medium of air could not be heard; this sound is also conveyed from ten to twenty times quicker through this solid than through the air. The earth likewise is a good conductor of sound; and we read of North American Indians laying their ears to the ground, to discover the approach either of human enemies or beasts of the forest. The miner hears through the solid rock the pickaxe of some neighbouring labourer, and the besieged detect the approach of a subterraneous enemy, from the sound conveyed by the earth. The surgeon applies the end *a* of the stethoscope to the chest of his patient, and hears the operation of breathing, and the rushing of the blood in the heart, by applying his ear to the end *b*, and ascertains the health or disease of the body with the same certainty as if he beheld the mechanism of the human breast. Some persons will place one end of a poker against a kettle, and the opposite end against their ear, when a loud tumultuous roaring and bubbling is heard, and the boiling of the water ascertained. Iron conveys sound

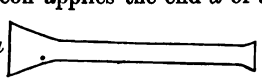
a  *b*

fig. 108.

seventeen times faster than air. Gutta percha is found to be one of the best materials for the tubular conveyance of sound; thus messages are sent to all parts of large warehouses, and to the bottom of mines, with as much ease as if speaking to a person in the same apartment. In churches, inside or outside of the pulpit, by placing a funnel, and from it conveying a main underneath the flooring, with small branch pipes, any number of persons rather deaf may hear the discourse of the clergyman as distinctly as if close to him. In fig. 109 we give an illustration of a gutta-percha ear-trumpet; the end *d* is inserted in the ear, and the words spoken in the large end *a* are reflected through the small tube *c c*.

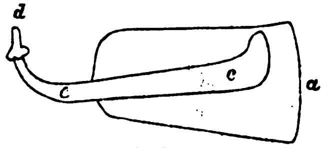


fig. 109.

Sound, if impeded in its progress by a body having a hole in it, passes through the opening, and then diverges as if from a centre; *a* passes through the hole in the shutter *b b*, and diverges to *c e*, the centre part passing in a direct line, *a ā*. If, with closed ears, the teeth or temple be placed against a long piece of timber, having at the other end a watch, the ticking will be distinctly heard. This is the case as long as the nerve of the ear is uninjured, the sonorous vibrations being conveyed by the solid bodies of the teeth and cranium to the nerves of the ear.

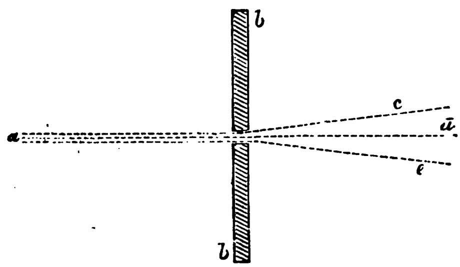


fig. 110.

Wind, as every one has practically experienced, retards or accelerates sound. The booming of cannon in a naval engagement has been heard at the distance of two hundred miles. A whisper and the report of a cannon travel at the same speed; thus a sound may be made loud by a powerful blow, but nothing is added to its velocity of propagation. At 62 degrees of Fahrenheit's thermometer sound travels at the rate of 1125 feet per second; a cannon-ball has about the same velocity, but at every foot its speed is lessened, whereas the noise accompanying its start on its destructive mission continues onward with the same speed as at first, only diminishing in intensity until it murmuringly dies away in space.

Sound travels a mile in about four seconds and three quarters, 12¾ miles, equal to 67,500 feet, in a minute, or 767 miles in an hour.

Thus if a flash of a musket be seen, the distance may be easily ascertained by timing the arrival of the report. When lightning bursts from the clouds, by laying the fingers on the wrist and counting each pulsation as a second until the thunder is heard, its distance may be pretty nearly calculated. But for every increase of one degree of temperature the velocity decreases one foot and a seventh in a second, and for every decrease of one degree of temperature it increases in velocity in the same quantity, which gives about 1160 feet velocity per second when the thermometer is at freezing-point.

On Mont Blanc the report of a pistol is not louder than that of a

squib. At the North Pole a conversation was carried on at a distance of a mile and a quarter. Sounds are better heard at night than during the day, from there being less variation of temperature.

In some travelling exhibitions a principle in acoustics was made a subject of interesting entertainment. Two persons were placed at a con-

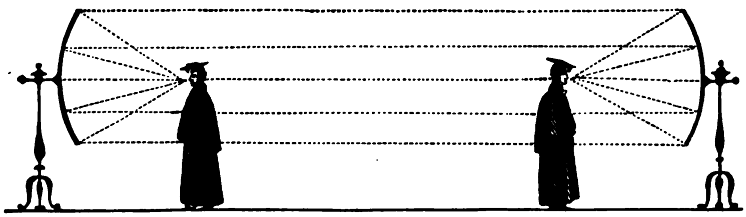


fig. 111.

siderable distance from each other, back to back, opposite two large concave mirrors, generally of polished brass; and upon one of the persons speaking in a whisper, the sound passed from the mouth, which was the focus, to the mirror near, when it was reflected back in parallel lines to the opposite distant mirror, and then reaching the focus was distinctly heard by the person placed there. A person standing between the mirrors was not aware of any sound whatever being made.

At the Polytechnic Institution the curve on one of the passages of the stairs conveys a whisper which cannot be heard by a party standing near; there is a small piece of wood fixed at each end for the application of the mouth or ear of the person whispering or listening.

There is an experiment, which by inexperienced persons is a very dangerous one, of breathing pure hydrogen, which has the effect, for some time, of so altering the voice as to astonish the experimenter as well as to amuse the audience, by the ridiculous sound of a stout man with a naturally deep bass voice speaking in the tones of a delicate affected young lady.

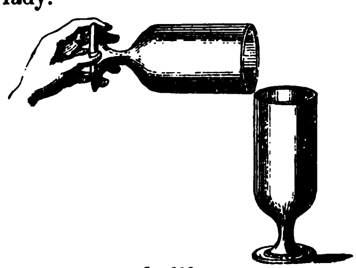


fig. 112.

If we take two glasses, having one in the hand and another standing on the table, then sound them both with a teaspoon or other hard body that will cause them to ring; while the sound is going on hold one over the other at right angles, and the sound instantly ceases, from the two vibrations crossing and destroying each other.

Again, put some water into a glass and ring it, when a musical note will be heard; put into the water a little carbonate of soda and tartaric acid, or any thing that will cause an effervescence, and hit the glass again, when all musical sound will be found gone, and a dull dead noise as if the glass was cracked in many parts. This is from the increased density on the inside of the glass created by the gas, the density on the outside remaining the same, and if practised by some mischievous youth, might alarm the nerves of a thrifty housewife.

If a violoncello be placed on a pianoforte while the latter is being played, it will emit the same notes struck upon the keys of the pianoforte, and even with corresponding chords.

By tapping a drinking-glass to hear its note, then stopping the sound by placing the finger on the rim, and immediately afterwards whistling the note at a short distance from the rim, the glass will recover the sound and continue it.

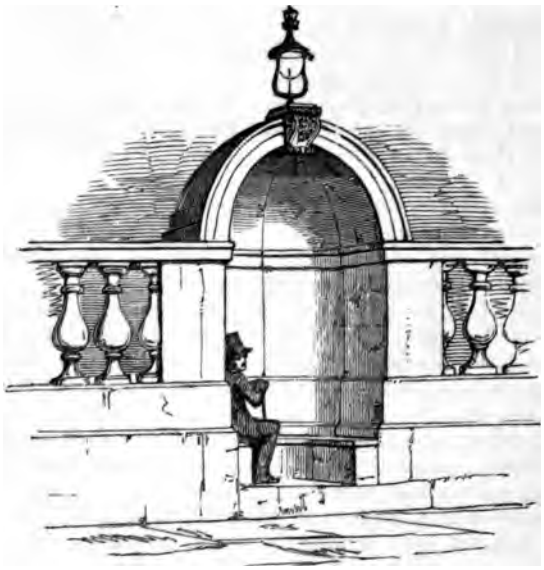
Sound an ordinary tumbler, and then blow powerfully at a short distance through a trumpet the same note for a short time, and the glass will be shivered into atoms. This feat was first accomplished by the late Mr. Harper, the celebrated trumpeter.

If a tuning-fork be held at the end of a cane placed upright on a table, and sounded, the note will be distinctly heard; but if the cane be bent so as to bring the fork to right angles with the table, then the sound ceases; upon restoring it to its former vertical position the sound again is audible.

A young officer of a ship lounging one day on deck about noon, and leaning his head against the taffrail, was confident he heard the sound of cannon firing. From the great distance, according to the ship's reckoning, that the vessel was from land, he at first thought he must be deceived; but at a regular interval again hearing the sound, he quickly entered the cabin and informed the captain and other officers; they came, listened, and were convinced of the fact. How to account for it was now the problem. On referring to the almanac they discovered it was the birthday of the king, George III., and that these guns must be fired in honour of the occasion from some fort. The nearest was that of Plymouth; and observations were immediately taken, when an error in the ship's reckoning was discovered of several hundreds of miles, being then only about 150 miles distant from the port from which the firing of guns was supposed to be heard. Thus to the quick ears, prompt conduct, and discrimination of the youth, a valuable vessel and the lives of many persons were undoubtedly saved. This is another instance of the surprising conveyance of sound through a liquid.

Were a railway-whistle sounded through a speaking-trumpet on occasions of danger, it would be heard full twenty miles distant, and thus be made the means of preventing some of those fearful collisions that have arisen from inability to convey the note of alarm with sufficient power. At sea, were a pistol fired through a speaking-trumpet, its roar would spread over the ocean to an incredible distance, either as a warning or for assistance; and this is gradually being adopted in vessels that do not carry heavy guns.

The *ear-trumpet* enables deaf persons to hear by the sound of the voice being brought to a focus at the narrow end, thus increasing the intensity of a sound upon the ear. The *speaking-trumpet* concentrates sound, and directs it to a particular part, above the voice of the storm. The alcoves on Westminster Bridge, long since removed, were so truly constructed in architectural proportions, that on a still evening a whisper in one might be heard in another on the opposite side of the road. But one of the most perfect instances of this peculiarity of sound is the Whispering-gallery of St. Paul's Cathedral, which is 430 feet in circumference. Seated in this gallery, the attendant, by whispering against the side 140 feet from the visitor, is heard as distinctly as if close to the ear.



Alcove on Westminster Bridge.

It will be obvious, that as sound takes a certain time to travel to the ear, a long file of soldiers marching to a tune will not all put down their feet at the same instant, but as the sound reaches them individually; thus there will be a difference between the tread of the man nearest to the music and of him who is at the farthest distance from it. In reviews of soldiers, all are aware that the report of the muskets fired does not reach the ear at the same time, but as a continuous sound. For this same reason a very large band of music is not well heard by an auditor, as the sounds from the nearest instrument arrive sooner than from those most distant; but this is compensated for by sitting at a distance, where the difference of the arrival of the sound from the farthest to the nearest instrument is more equalised.

The ancients not being able to account for the phenomenon of an *Echo*, clothed their ignorance in the mantle of mythology, saying it was a myth whose loquacity displeased Jupiter, therefore she was deprived of the power of speech by Juno, dwelling concealed among the rocks, and only permitted to answer to the questions which were put to her; her love of Narcissus being repulsed, she pined away and was changed into a stone, which still retained the power of speech. Such is the fable which science has exploded.

As the waves of water are thrown back when they meet with an obstruction having a smooth surface, so are the waves of air creative of sound; and this constitutes an echo.

The flat sides of rocks, mountains, caves, domes, and arches, thus reflect sounds. At Lurley, on the Rhine, a noise made on one side of the river is echoed and re-echoed across and across in a zigzag manner, proceeding onwards about six times, when it dies away. In some places the report of a pistol has been counted as many as forty times. As sound

travels at the rate of 1125 feet in a second, by timing the arrival of an echo to the ear the distance of places may be ascertained. If the waves of air strike obliquely against a wall, they will be reflected obliquely on the other side, the angles of incidence and reflection being equal.

The irregularity of surface in a wall may be so great as to prevent entirely any distinct reflection : this is the case in theatres, the walls of which are provided with broken surfaces to prevent the echo. A regular concave surface concentrates sound; as suppose *a b*, fig. 114, to be part of a concave wall, sounds proceeding from *c d f e*, *g h l*, strike the concave surface of *ab*, and are concentrated to the focus *k*: in like manner a speaker placed at *k* is enabled to make his hearers distinguish his words better by placing a concave reflector behind him; the waves of sound strike the reflector, and are sent into the room in parallel waves as in the diagram. In a perfectly circular room the waves of sound are concentrated in the centre. Elliptical or oval-shaped rooms present a curious property in the concentration of waves of sound. This property

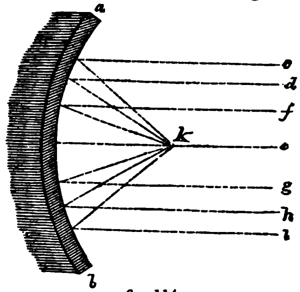


fig. 114.

is such that waves of sound proceeding from one of the foci *c* of an elliptical room *a b*, fig. 115, after reflection at various points, as from the lines *e*, *f*, *g*, *h*, *i*, are all concentrated in the other focus *d*; thus a person whispering at *d* can be heard distinctly by another standing at *c*, although it is not audible to other parties elsewhere situated in the room.

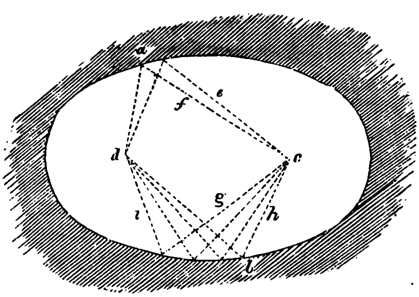


fig. 115.

As we commonly utter about three syllables and a half, or seven half-syllables in a second, the echo of this number of syllables will be distinctly heard in that time by a person situated at the distance of about 560 feet, half the number of feet sound travels in a second; but if a sentence be continued, the sounds will so commingle as to be confused.

THE HUMAN EAR.

The external passage of the ear is terminated by the membrana tympani, which is very elastic, having behind it the tympanum; and from this is a tube for air from the mouth, which accounts for persons aiding their hearing by opening the mouth. Both the cochlea and vestibule are filled with a watery fluid, in which are expanded the fibres of the auditory nerve. When sounds reach the membrana tympani it is set in motion, which is communicated to the small bones, named after their fancied resemblance to certain implements, the *malleus*, *incus*, *orbiculare*, and *stapes*. Their use is to transmit the vibrations of sound from the external membrane to the fluid contained in the internal ear, and to the nerve spread out in this

fluid. They have another use that a single bone could not be made to perform; namely, to permit the lightening and relaxing of the tympanic membrane, and thus adapt it either to resist the impulse of a very loud sound or a more gentle one. Mammals alone have external ears. Birds have but a simple aperture; in reptiles and fishes the ear is covered over with skin: in many animals, crabs for example, it consists merely of a vesicle filled with fluid, throughout which the nerve is spread. In insects, and the lower orders of animals, with but few exceptions, this organ has not been satisfactorily made out.

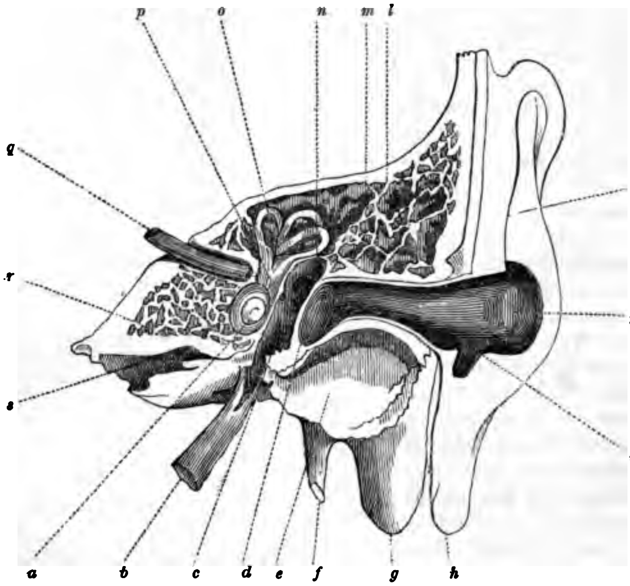


fig. 116. A vertical section of the human ear.

a. Is named the cochlea, from its resemblance to a small shell.
b. Eustachian tube, leading from the tympanum to the back of the pharynx.
c. The tympanum, in which are four small bones: the malleus, or hammer; the incus, or anvil; the orbiculare, or little ring; and the stapes, or stirrup. In it are two openings, called fenestra ovalis and rotunda.
d. The membrana tympani.
e. The glenoid fossa of the temporal bone, in which the lower jaw is articulated.
f. The styloid process of the temporal bone.
g. The mastoid process of the temporal bone.
h. External lobe of the ear.
i. The antitragus.
j. Conch of or entrance into the ear.
k. The tragus.
l, m, r. Petrous portion of the temporal bone.
n. Opening from the cavity of the tympanum to the cells of the petrous bone.
o. Semicircular canals.
p. The vestibule.
q. The auditory nerve.
s. The canal in which the internal carotid artery passes to enter the cranium.

Before closing this portion of the subject, we may relate as appropriate the accounts given of the celebrated ear of the tyrant Dionysius. He made a subterraneous cave in a rock (said to be still preserved), in the form of a human ear, which measured 80 feet in height and 250 feet in length. The sounds of this subterranean cave were all necessarily directed to one common tympanum, which had a communication with an adjoining room where Dionysius spent the greater part of his time, to hear whatever was said by those whom his suspicion and cruelty had confined. The artists that had been employed in making this cave were all put to death by order of the tyrant, for fear of their revealing to what purposes a work of such uncommon construction was to be appropriated.

MUSIC.

Such is the delicacy of the human ear, that it can distinguish between two sounds, the one having 400 vibrations in a second and the other 405; also the different instruments playing the same note, and between two of the same kind of instruments when playing together; or detect a single voice amid hundreds all singing the same tune. In fact, the hearers of an orchestra are employed in hearing and discriminating between various rates of succession in the undulations of the air around them, from 60 to 2000 per second.

If a piece of catgut or wire be slightly stretched, and then hit or pulled at the middle, it will be seen to vibrate, and each pulse of the air be separately heard; but when tightened and struck or pulled, the vibrations follow in quick succession, only a broad indistinct line is seen, and the pulses of the air follow so rapidly, that they are felt on the ear as one tone, which is called a note. The uniformity of tones in elastic strings arises from large vibrations occupying about the same time as smaller ones. When the vibrations are rapid, the sound is loud, from the pulses of the air being more forcible. The regularity of succession of the pulses of the air produces the pleasing effects of a tone, as the buzzing heard from the quick and regular movement of the wing of a fly.

If we examine the strings of a violin, we see that one is carefully wound round with a fine metal wire; this makes it thick and heavy; hence it must have a slower vibration than thinner ones, therefore produces a bass or grave note; and the others vary in thickness, consequently have quicker vibrations and sound, higher or sharper, and are screwed to a certain tension to assist the perfection of tone. Then a quicker vibration is produced from shortening the string by the pressure of the finger or by tightening, and slower vibrations by lengthening the string or slackening it.

There are seven primary notes in music, which are those that would be used by a person who had not learnt it scientifically. They are expressed in singing by the names of Do, Re, Mi, Fa, Sol, La, Si, and in printed music by notes arranged and named as the following letters of the alphabet, C, D, E, F, G, A, B.

If a musical string be of such a length and tension that it gives out in a second 258 vibrations, according to M. Biot the note will be C; but if only half the length be used, the vibrations will be twice as many as before, 516; this commences a new series of notes, another C or eighth letter, and is termed an octave. If the string be reduced to eight-ninths there will be 290 vibrations, the note D; if to four-fifths 322 vibrations, the note E; if to three-fourths 344 vibrations, the note F; if to two-thirds 387 vibrations, the note G; if to three-fifths 430 vibrations, the note A; and if to eight-fifteenths 483 vibrations, the note B. A string when touched not only gives out its primary note, but subordinate notes belonging to its half, third, and fourth. By watching the motion of a string, it will be found vibrating not only along its whole length, but also at the same time vibrating in shorter lengths, thus sometimes the subordinate notes are more distinctly heard for a time than the original. It is this natural and self-acting division of a string into equal parts that produces the wild music of the *Æolian harp*. The cords are tuned to the same pitch, but as the passing breeze touches various parts, either a perfect note

is heard, or some of the divisions in vibration of which each string is susceptible.

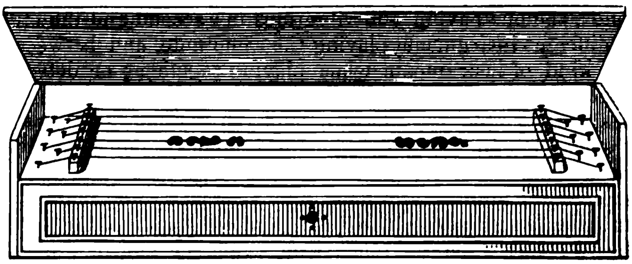


fig. 117. The Æolian Harp.

The following description of the Æolian harp by Dr. Arnott is so beautiful in language that we cannot resist quoting it: "When the harp is suspended among trees, or in any situation where the fluctuating breeze may reach it, each string, according to the manner in which it receives the blast, sounds either entire, or breaks into some of the simple divisions just described; the result of which is the production of the most pleasing combination and succession of sounds that fancy has ever listened to or perhaps conceived. After a pause this fairy harp is often heard beginning with a low and solemn note like the bass of distant music in the sky; the sound then swells as if approaching, and other tones break forth, mingling with the first; and with each other. In the combined and varying strain, sometimes one sweet note predominates and sometimes another, as if single musicians alternately led the band; and the concert often seems to approach and again to recede, until with the unequal breeze it dies away, and all is hushed again. It is no wonder that the ancients, who understood not the nature of air, nor consequently even of simple sound, should have deemed the music of the Æolian harp supernatural, and, in their warm imaginations, should have supposed that it was the strain of invisible beings from above, descended in the stillness of evening or night to commune with men in a heavenly language of soul intelligible to both. But even now that we understand it well, there are few persons so insensible to what is delicate and beautiful in nature, as to listen to this wild music without emotion; while to the informed ear it is additionally delightful, as affording a fine illustration of those laws of sound which human ingenuity at last has traced."

From there being no time observed in the music of the Æolian harp, the airs cannot be committed to memory. As the above fascinating account of the simple instrument's powers of divine discourse may create a desire in some of our readers to be possessed of one, we give the following description of the mode of their construction from Knight's *Cyclopædia of Industry*. "Let a box be made of thin deal, of a length exactly answering to the window in which it is intended to be placed, four or five inches in depth, and five or six in width. Glue on it, at the extremities of the top, two pieces of oak, about half an inch high and a quarter of an inch thick, to serve as bridges for the strings; and inside, at each end, glue two pieces of beech about an inch square, and of length equal to the width of the box, which are to hold the pegs. Into one of these bridges fix as many pegs,

such as are used in a pianoforte, though not so large, as there are to be strings; and into the other, fasten as many small brass pins, to which attach one end of the strings. Then string the instrument with small catgut, or *first* fiddle-strings, fixing one end of them, and twisting the other round the opposite peg. These strings, which should not be drawn tight, must be tuned in unison. To procure a proper passage for the wind, a thin board, supported by four pegs, is placed over the strings, at about three inches distance from the sounding-board. The instrument must be exposed to the wind at a window partly open; and to increase the force of the current of air, either the door of the room, or an opposite window, should be opened. When the wind blows, the strings begin to sound in unison; but as the force of the current increases, the sound changes into a pleasing admixture of all the notes of the diatonic scale, ascending and descending, and these often unite in the most delightful harmonic combinations."

We have before remarked, that the lowest note that can be heard has 30 vibrations in a second, and the highest has 8192, between which there are about eight octaves. The human voice possesses a power of from two to three octaves, a man having a pitch of an octave lower than a woman. An organ-pipe 32 feet long produces a very deep note, having waves of sound 32 feet long, and the same number of vibrations in a second; this is note CCC; its octave has 64 vibrations in the same time, its third 40, and so on.

Although the same note as to pitch or tone may be given by a skilful player and a mere amateur, by producing a given number of vibrations, yet there is a peculiarity, a difference, conveyed to the sense of hearing from the manner in which the air is acted upon. The late Dr. Young examined the string of a violin when in motion, and by throwing a beam of light upon it, and marking the motion of the bright spot which it made, he found that the string rarely vibrated in the same plane, but that the middle points would describe various and very complicated curves, corresponding to different manners of drawing the bow. Thus, then, must arise the crude and the polished tone.

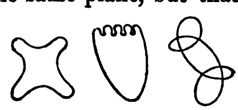


fig. 118.

The simple scale of seven notes that we have given, is that of nature; for wherever man is found, and has expressed himself in musical language, they are the notes he uses. The music of the human voice is produced by the vibration of two membranes at the top of the windpipe, having an opening between them for the passage of the air. According to the degree of tension of these membranes, and the size of the opening, is the voice bass or treble; and according to the note he utters, are the vibrations. Thirds, fifths, and octaves harmonise with each other, when sounded together, more than other notes, from their vibrations being more in proportion, which renders the sounds in a greater degree gratifying to the ear. Time gives a foreknowledge of the expected sound, and thus is pleasing to the mind.

Musical sounds are produced in many ways, as by elastic metal wires, prepared strings of animal intestines; pieces of metal cut like a comb, having a barrel with prongs to cause them to vibrate; the stretched skins of sheep; hollow vessels of brass, confining a column of air in a tube; a glass or pieces of glass, a bell; or, as in the organ, admitting a column of air from bellows to pipes by the action of keys; or by thin pieces of reeds or

metal, which vibrate from the breath being applied, and according to their elasticity, weight, or length, give forth their peculiar tones; and these different means of producing sounds give rise to the varied shapes of musical instruments.

Sound moves in waves; and if we draw a line through the part where the waves commence to rise, and another where they fall, that line is termed the nodal, and the meeting of the points of elevation and depression the nodi.

If a string 24 inches in length be touched at 12 inches while vibrating, then each of the 12 inches will vibrate twice as quickly as the entire string was previously vibrating, and give forth the same note an octave higher; touch the string at 6 inches from either end, and both the 6-inch length and the 18-inch will give the same note, the one having more waves than the other; that is, on the 18-inch side there are two nodal points and three waves, and on the 6-inch side one wave. Again, if the finger be lightly placed on the string at 3 inches from either end, or at 9 inches from one end and 15 from another, another octave will be attained; while by touching the string at intermediate points to those last mentioned, nearly all the other notes in the upper octaves may be obtained.

If those soundless bodies lead and wood be hollowed and formed into the shape of a bell, they will, on being struck, give forth musical sounds, provided they be not made too thin.

When a jet of hydrogen gas is lit, an explosive sound is heard, and while burning, a series of explosions are going on; but as the surrounding air becomes heated, and consequently rarefied, these are less audible. On placing a glass tube above a burning jet of hydrogen, a musical sound is heard; and as the tube is raised or lowered, a most pleasing effect is produced in the increase and dying away of the musical tones. In fact, the air of the apartment is as it were filled with divine discourse, and in wonderment the eyes search all around for the cause and part from whence issue the sweet sounds. This is caused by the air inside and outside the tube becoming heated, and the pulses from the explosion being communicated to the ear as musical sounds through the denser air of the room.

In another experiment we may refer to, that of an effervescing mixture placed in a glass containing a little water, it will be found that from the density of the atmosphere outside the glass differing from that within, no musical note could be produced by striking the glass. It is a singular fact in all wind instruments, that they differ from the divinest of harmony, the human voice, by the sound being created at the entrance of the pipe instead of at the end; thus in the organ, flute, flageolet, clarionet, and others, the air, after creating the sound, passes down the pipe. This idea striking a party, various experiments were made to produce sounds at the end instead of the commencement of a pipe, and some success was attained in a vulcanised india-rubber pipe filled with water. In fact, such was the result, that the letters of the alphabet could be distinguished in a singular gruff pronunciation.

Another attempt was made to imitate the harmony of the voice of man, which the inventor has called "The Euphonia." It is stated by Professor Faber "to be the result of twenty-five years' labour!" but it is in vain to apply the *cui bono* to a matter like this. It is quite true that mechanical figures, in heads and turbans, with their lungs in red baize and worked by machinery, are not in themselves utilities—the more particularly as their

talking machinery requires the impulse of a real living and talking man, who might more conveniently have done the talking at first hand. As an

fig. 119. The Euphonia.

example of inductive and mechanical skill, however, such an exhibition as this is well deserving of attention; and there is no difficulty, besides, in imagining a number of purposes to which the discovery of any artificial means for producing vocal articulation might be applied with valuable effect. It is, in any case, an old scientific problem; and any thing that brings us nearer to its solution would have an interest, were it for that reason alone. We believe this invention of Professor Faber comes closer to that result than any previous 'instrument made with hands.' Still, this is, like all similar attempts which have preceded it, only an approximation, though a nearer approximation, to the thing proposed. It requires all our sense of the ingenuity and perseverance which have been bestowed on the work, to induce our assent to the proposition which calls the voice a human voice; and it is only remarkable as the result of contriving skill and scientific patience.

We may add, that the concert pitch has progressively risen all over the world, but in England it always is higher than any other nation. This peculiarity makes it difficult for foreigners to sing to an accompaniment played by an English orchestra.

THE VOICE AND SPEECH.

Dr. Arnott, in his admirable treatise on Physics, observes that "the chest and air-passages, with their parts, constitute the organs of voice and speech.

An inquirer into the constitution of the universe around him meets with few things calculated more to surprise him than the faculty in the human mind by which it can so closely associate the ideas of objects with any arbitrary signs, that the ideas are afterwards excited by the signs almost as vividly as by the objects themselves. The inhabitants of China, for instance, have contrived many thousand grotesque characters, and determined what object each one shall recall; and a person who by study becomes familiar with them, may have his bodily eye poring over pages of crooked and unseemly scratches, while his mental eye sees only a pleasing succession of the most beautiful imagery of nature; and the characters are intelligible to the deaf and dumb man as well as to him who speaks; and they serve as media of thoughts and communications through many provinces and countries of which the spoken languages have no common resemblance.

If the ready resemblance of visible marks be wonderful, which have permanent existence, and often a certain resemblance of the things signified, how much more wonderful is it that an audible sign, that is, a passing sound or fugitive breath, should serve as well; and that by a succession of mere sounds, different in every country and changing from age to age, any train of thoughts may be made to pass through the minds of an audience, so as to leave impressions almost as strong as from realities! Such, however, is the fact; and it is greatly owing to this and to a corresponding faculty of producing easily a sufficient number of distinguishable sounds, that man owes his elevation above the brutes of the field.

His godlike powers of intellect would have remained dormant and unknown, had he wanted the power of comparing his invisible thoughts with those of his fellow-men, and of arranging and recording them by means of signs.

Written language is a double remove from the objects themselves, being *visible signs*, not of things, but of the *audible signs*.

The admirable apparatus by which man is enabled to produce a sufficient variety of sounds to answer his purposes passes generally under the title of *the organs of speech*; because the combination of sounds which have meanings assigned to them is called speech. It consists of the chest for containing air, of the larynx or cartilaginous box at the top of the windpipe for producing the voice, and of the short tube of the mouth for modifying it.

In the chapter on acoustics we explained that sound is the name given to the effect produced upon the ear by certain tremblings conveyed to it, generally through the medium of the air; and we explained how air, rushing from the human lungs through the opening at the top of the windpipe, may be modified, at the will of the individual, in a great variety of ways—a variety which is, however, still very simple.

The modifications of voice easily made, and easily distinguishable by

the ear, and therefore fit elements of language, are about fifty in number; but no single language contains more than about half of them. They are divisible into two very distinct and nearly equal classes, called *vowels* and *consonants.*

Those of the first class are the simple voice issuing through the open mouth, and influenced only by the degrees in which the mouth is opened and elongated. They may be continued as long as there is breath to issue from the chest, and therefore are named *vowels* or *calling sounds.* The Roman letters A E I O U, as generally pronounced on the continent of Europe, indicate the most easily distinguishable vowels. Sounds passing through the mouth while in its most natural state of relaxation are heard as the modification expressed there by the Roman E (or the *a* of the English word *care*); if the mouth be then widened, it becomes A (of the English word *bar*); if narrowed, we hear I (or *ee* of the English word *seem*); if the mouth be elongated, and at the same time widened, we hear O; and if elongated and narrowed, we hear U (of the English word *rude*). The possible number of vowels, however, is as great as the possible degree in which the dimensions of the mouth may be altered. About twenty of them are sufficiently distinguishable; but few languages comprehend so many. Modern art can produce the vowel-sound mechanically, by means of tubes of certain dimensions.

The alphabets of Europe are very faulty in not using the same characters for the same sounds, and in not having a character for each sound, according to the true intent of the alphabet. In English one letter is used for several sounds, as A in *water, far, fat, fate,* which are four perfectly distinct sounds.

In repeating the English alphabet, the A is pronounced as a broad E of the Italians, and the E as the I. The English vowel I is the diphthong AI of the more correct alphabets; and the English U is the diphthong IU. In consequence of the changes which have taken place in England in the meaning of the Roman letters, the increased difficulty natives experience in learning modern continental languages is ridiculous, and unintelligible to all but themselves. The same cause renders the pronunciation of English difficult to foreigners, and thus much restricts the cultivation of English literature in other countries.

To explain the second class of the modifications of sound, called *consonants,* we may remark, that while any continued or vowel sound is passing through the mouth, if it be interrupted, whether by a complete closure of the mouth or an approximation of parts, the effect on the ear of a listener is so exceedingly different, according to the situation in the mouth where the interruption occurs, and to the manner in which it occurs, that many most distinct modifications thence arise. Thus any continued sound, as A, if arrested by a closure of the mouth at the external confine or lips, is heard to terminate with the modification expressed by the letter P,—that is, the syllable AP has been pronounced; but if, under similar circumstances, the closure be made at the back of the mouth by the tongue rising against the palate, we hear the modification expressed by the letter K, and the syllable AK has been pronounced; and if the closure be made in the middle of the mouth by the tip of the tongue rising against the roof, the sound expressed by T is produced, and the syllable AT is heard; and so of others. It is to be remarked also, that the ear is equally sen-

sible of the peculiarities, whether the closure precedes the continued sound or follows it; that is to say, whether the syllables pronounced are AP, AT, AK, or PA, TA, KA. The modifications of which we are now speaking appear, then, not to be really sounds, but only manners of beginning and ending sounds; and it is because they can thus be perceived only in connexion with vocal sounds that they are called consonants.

There are in the mouth, considered as a vocal tube, three situations in which interruptions of the voice or breath may most conveniently be made, and there are six modes of making it at each; so that eighteen distinct interruptive modifications or consonants hence arise. These we shall now describe.

The three great *oral positions*, as they may be called, are :—

1. At the external confine of the mouth, or lips, giving the *labial* articulations.

2. In the middle of the mouth, where the tip of the tongue approaches the palate behind the teeth, producing the *palatal* articulations.

3. Near the back of the mouth, where the body of the tongue approaches the palate, giving the *guttural* articulations.

The *six modes* in which the voice or breath may be affected in passing through each of the three positions of the mouth are the following :—

1. A *sudden stoppage*, producing what may be called a *mute* articulation, viz. P in the labial position, T in the palatal, and K in the guttural. In pronouncing experimentally, it is better that the vowel be heard before the consonant than after it, as by sounding the syllable AB instead of BA. See the general table of articulations on next page. The table may be considered as representing the tube of the mouth, with the letters so placed in it as to shew in what situations they are severally produced. A mute may also be made by stopping the breath exactly at the teeth, producing thus a *dental mute;* but it is hardly distinguishable from the *palatal mute* just behind it, and being less perfect, is not used. Some awkward speakers substitute it for the proper mute, and are said to speak thick. If the sides of the tongue be depressed after it has taken the position required for T, the sound L is produced.

2. A sudden shutting, as in the previous case, but the voice being allowed to continue until the part of the mouth behind the closures be distended with air. This produces the *semi-mutes* B, D, and G (in its hard sound, as in *pig*), for the three positions. There might be a dental *half-mute*, but it is of no more use than the *dental mute*, and for the same reasons.

3. The positions closed, as for the mutes, while sound is allowed to pass by the nose. Thus arise the *semi-vowels* or *nasals*, M, N, NG, for these three positions. NG (as in *king*) is a simple sound, although our imperfect alphabet has no single letter for it. The nasal sound of the French language, which gives it so great a peculiarity, approximates to the English NG, but differs from it in the sound passing by the mouth as well as by the nose. It is represented by *ng* in the table.

4. Breath only, or whisper, allowed to pass at the three oral positions nearly closed. Hence come the sounds which we call *aspirates*, viz. F, TH, and CH; the two latter are simple sounds, although expressed in English by two letters. The TH is heard in the word bath, and is the ϑ of the Greeks. The CH is heard in the Scotch word *loch*, in the German

ich, and is the χ of the Greeks. The *soft palatal aspirate* TH is not so easily made as the *dental*, which is heard on pressing the tongue gently against the teeth, and allowing the breath to pass all round; the *dental*, therefore, is used in preference to the *palatal*. The letter S is the *hard palatal aspirate*, and differs from the *soft aspirate* TH in the breath being made to issue with greater force, and only by a narrow space over the centre of a rigid tongue, instead of on all sides of a soft tongue, as for TH. French people, on first attempting to pronounce TH, always substitute for it the S or the Z (which is nearly related to S, as explained below). The author has enabled several of them to pronounce the TH at once, and perfectly, by explaining its nature as above. If we depress the sides of the tongue while pronouncing S, we make the simple sound expressed by the English double letter SH; just as by depressing the sides of the tongue while making T we produce L.

5. Using *voice* in the same manner as *breath*, or whisper, for the aspirates. This produces the sounds called *vocal aspirates*, is heard in *bathe*, as contrasted with the *simple aspirates* in *bath*: Z comes from the S position, only with *sound* instead of *breath;* SH pronounced with *voice* becomes the J of the French in the word *je*, or the sound heard in the middle of the English word *vision*. GH is a simple sound used in German, but not in English.

6. Shaking the approaching parts in the three positions. We thus make *vibratory sounds*, of which the middle position gives the common R, —the only one of them used in England. Some bad speakers of English, however, make the *labial vibratory* by shaking the P in such words as *property;* and many use the *guttural*, which is the *burr* of Northumberland, and the common affectation in the Parisian speech called *parler gras*, or *grasseyer*.

TABLE OF ARTICULATIONS.

Labial.	Palatal.	Guttural.	
P	T, L	K	Mute.
B	D	G	Semimute.
M	N	ng, m	Semivowel or nasal.
F	th, s, sh	ch, H	Aspirate.
V	th, z, J	gh	Vocal aspirate.
pr	R	ghr	Vibratory

ADDITIONAL REMARKS.

The sound of H does not belong to any of the three positions; and, indeed, is merely a forcible passing of the breath through the back part of the mouth or throat.

CH, in such words as *chain*, means T before SH.

J, as heard in the English word *John*, is a compound sound, viz. D before the simple J of the table, which is S of *vision*.

LL. The liquid or double LL of the French, as heard in the word *paille*, is merely L with the letter Y begun to be pronounced after it. It

is heard in the English word *billiard* and *halyard*, and would be their terminating liquid were the syllable *ard* not pronounced.

GN. The soft GN of the Italians and French is the English N with Y begun to be pronounced after it. It is heard in our word *tan-yard;* and in the Italian words *pegno*, *bagnio;* and in the French word *craignent*.

C in English stands always either for S or K, as in the words *certain* and *car*, and has no sounds proper to itself.

Q expresses a compound sound, viz. of the letter K with U following it.

The consonants are best heard by sounding them with voice before them; that is to say, by making them rather terminate a syllable than begin it; pronouncing B, D, G thus, *eb*, *ed*, *eg*, rather than their common alphabetical names, *be*, *de*, *ge*.

The labial sounds may be made either by the two lips, or by one lip and opposite teeth.

F may be pronounced, for instance, by the lips only, or by the lips and teeth; and some persons awkwardly make it by the under teeth and upper lip.

The letters Y and I, in most modern languages, stand for nearly the same sound. In English, for instance, *bullion* and *minion* might be written *bullyon* and *minyon* without suggesting a change of pronunciation. In the words *yard*, *you*, *yes*, &c., the Y is a short I, very closely joined to the following syllable.—W is also thus a short U, as perceived in the words *war*, *we*, &c."

Thus eloquently does the learned doctor conclude:—

"By language fathers have communicated their gathered observations to their children; and these again, with gradual accumulations, to new descendants; and when, after many ages, the precious store had increased until the simple powers of memory could retain no more, the art of writing arose, making language visible and permanent, and enlarging without limits the receptacles of wisdom; and then the art of printing came, to roll the still swelling flood of knowledge into every hamlet and every hut. Language thus, at the present moment of the world's existence, may be said to bind the whole human race of uncounted millions into one gigantic rational being, whose memory reaches to the beginning of written record, and retains imperishably the important events that have occurred; whose judgment, analysing the treasures of memory, has already discovered many of the sublime and unchanging laws of nature, and has built on them the arts of life, and through them, piercing far into futurity, sees distinctly events that are to come; and whose eyes and ears and observant mind, at this moment, in every corner of the earth, are watching and recording new phenomena, for the purpose of still better comprehending the magnificence and simplicity and beauty of creation."

HEAT.

THE self-sufficiency of man and his boastful pride of knowledge are humbled when he is asked the questions, what is gravity? what is light? what is life? what is heat?

Amid the profusion of benefits heaped by the Almighty on the last object of his creation—man—heat ranks pre-eminently as a valuable boon; for it is that which causes the fruitfulness of the earth by awakening the dormant and mysterious principle of life—it is the harbinger and parent of beauty, plenty, and joy—its effects give in teeming profusion, as Nature "unfolds her robe," the splendour of spring, the richness of summer, and the fulness of autumn—its presence fills the heavens with rapturous songs of praise, and it inspires with industry the will and hand of man. By it is food rendered fitting for the human stomach, and the metal rendered ductile which is fabricated into engines that work with the precision of human intellect. In the absence of heat, all is sterility, solidity, and silence; Nature ceases her active life, and slumbers as if in a sleep of death.

Heat permeates the whole of the material world, yet it can only be discovered by its presence in some material substance. It adds nothing to the weight of any object where it is diffused, which has led to controversies respecting its material or separate existence, being asserted to be merely motion, as the phenomenon of sound is known to be. This argument is supported by the well-known fact of savages rubbing two pieces of wood together to produce fire, and Sir H. Davy melting ice in a room cooled below freezing-point by rubbing them against each other, and by Count Rumford boiling water by rubbing a blunt borer against metal sunk in the water. Hence they reason that heat is a vibratory or oscillatory motion of the particles of matter, which in extent and velocity varies, but is always seeking to equalise itself by communicating its properties to surrounding bodies, and that it spreads by means of waves through the ether with which space is supposed to be filled. On the other hand it is argued, that it is matter of extreme minuteness and thinness, possessed of indefinite self-repulsive powers; that it is ever acting in opposition to the attraction of cohesion, and that upon it depends the distance between the constituent particles of bodies; that as it enters between the atoms of bodies, promoting their separation, it opposes and balances the force of attraction or gravity, so that no additional weight is felt by adding or withdrawing heat. That heat radiates through a vacuum; that it can be, as it were, squeezed out of a mass, as when air is compressed, a match may be lighted from the heat evolved; or on two bodies being mixed and heat given out, less space is required according to the heat disengaged. That it is a subtle fluid, or ether, whose parts are very repulsive of each other, and therefore spreads widely and instantaneously when liberated, as in the case of gunpowder being exploded; and that its presence is every where softening, expanding, changing, and turning to gas various bodies.

Again, it is asserted, that as iron which is rendered hot increases in bulk, as water when heated fills more space, and air when warmed expands with a power to burst the bladder in which the experiment may be made, the laws of heat consequently differ from those of sound, and a material

body occupies the space between the atoms of matter composing a substance.

Some writers make a distinction between the word caloric and heat. Caloric, they say, is the matter of heat; and heat the sensation produced upon our organs by the motion of caloric disengaged from surrounding bodies.

There is a constant tendency to an equilibrium of heat; thus if we lay our hand on a piece of cold marble, the heat passes out of the hand into the marble, and we say our hand feels cold, as we have lost the heat it formerly possessed; but cold is nothing positive, it is merely the want of heat, which may be increased until organic life be destroyed. If we touch a warm body, then the heat passes from it into the hand, and we feel the sensation of warmth; but heat may be applied to bodies until it destroys life and organisation. If the hand touch a body of the same heat as itself, then there is no motion of caloric, and we say the temperature is equal. But a change in the temperature affects the repulsion and attraction of bodies; thus the heat of the sun causes the repulsion of the atoms of iron composing the tubes of the Britannia Bridge, and they lengthen out at mid-day, while as the cold of evening advances they again contract. When bodies at a certain temperature occupy a certain space, they are said to be in equilibrium between the two forces, the attraction of cohesion and the repulsion of heat, the forces neither attracting nor repelling each other.

The particular temperatures of bodies are measured and compared with each other, and thus a change is discovered. A simple, beautiful little instrument is used for this purpose, called a mercurial or spirit thermometer, with a bulb *b b* containing mercury *a*, having a long narrow neck to which is appended a graduated scale *d d*, marked from the point at which the mercury sinks 32 degrees below freezing-point, and at the part to which it rises in boiling water, the intervening spaces being arbitrary degrees. With this instrument the increase or decrease of temperature is known, and consequently the increase or decrease of bulk in the whole mass may be estimated.

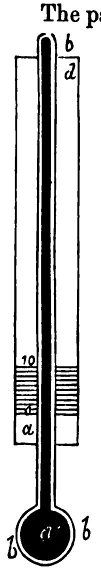


fig. 120.

Mercurial thermometers are those in most general use for common purposes: the fixed points are the temperatures of melting snow or ice, called the freezing-point; and that of pure boiling water, named the boiling-point. The spaces between unfortunately differ in the length of degrees on the scale of graduation in this country from those on the Continent. Here we use the Dane Fahrenheit's thermometer; he starts at 0 zero, extreme cold, rising 32 degrees he has freezing-point, at 56 degrees temperate heat, 76 degrees summer heat, 98 degrees blood heat, 112 degrees fever heat, 176 degrees spirit boils, 212 degrees boiling-point of water; thus he divides the two points of freezing and boiling into 180 parts. Reaumur commences his scale at 0, which he makes the freezing-point, and divides up to boiling-point into 80 equal parts. The Swedish thermometer, called the Centigrade, divides the space between the two points into 100 exact parts or degrees. As sometimes the one scale and sometimes the other is given, it is well to know how to compare them with that with which we are best

acquainted; therefore to change Fahrenheit's into Reaumur's scale, multiply the number of degrees above or below 32 by 4, and divide by 9. To change Reaumur's into Fahrenheit's scale, multiply the degree by 9, divide by 4, and add 32. To change Fahrenheit into the Centigrade, multiply the degrees above or below 32 degrees by 5, and divide by 9. To change the Centigrade into Fahrenheit, multiply by 9, divide by 5, and add 32. The utmost extent of the mercurial thermometer is the points at which quicksilver boils and freezes; that is, as high as 600 and as low as 40 degrees below 0; consequently the thermometer in extent can range 640 degrees. It is singular that, in forming accurate thermometers, they are placed upright in pure melting snow or ice; the fluid in the tube contracts and takes up a settled position, to which on every immersion it returns, from the temperature being always the same; but if marked immediately, and some months afterwards again tested, it will be found from one-half to two degrees above the mark. This is supposed to arise from the contraction of the bulb, which is gradually brought about from the constant pressure of the atmosphere; hence twelve months are allowed to elapse before the mark is permanently decided upon. The boiling-point is found by laying the thermometer in the steam just above the surface of distilled boiling water, the barometer standing at 30 inches, until the mercury becomes stationary; were it dipped in, as the heat decreases with the depth, it would not be accurate.

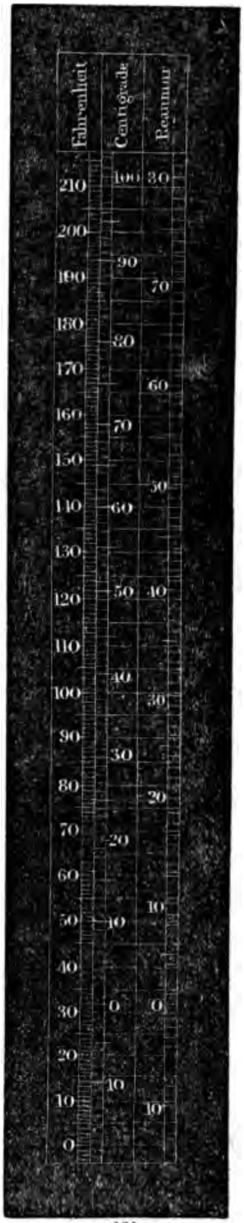


Fig. 121.

England, Holland, and North America adopt Fahrenheit's scale; Sweden, Celsius's centigrade; and France and Germany, Reaumur's or the centigrade scales. Fig. 121 shews the three scales of the thermometer.

For all ordinary purposes the mercurial thermometer is found to answer well; but we may be asked, if solids are so affected by changes of temperature, must not the glass of which the thermometer is formed also vary? This certainly is the case; but so slightly as to give a degree of accuracy that no other transparent body with which we are acquainted would answer the purpose so well.

Mercury, possessing a uniformity of expansion, is found the best material to indicate the variations of temperature by any change in its volume, as well as being a good conductor of heat, and therefore is used for thermometers.

A tube of glass being procured having a very regular but extremely

small bore, one end is blown out to a bulb, the diameter of which is made large comparatively to the diameter of the tube. The bulb and stem is then heated to expand the air within it, after which the open end is quickly plunged into a basin of mercury. The glass then being permitted to cool, the internal air contracts, and the atmosphere pressing on the surface of the mercury in the basin, a little of it is forced up the tube. A small quantity of mercury being thus got into the bulb, the mercury is then boiled in the bulb, which expels all atmospheric air and thoroughly dries the tube. The open end is plunged again into the basin of mercury, and on cooling more mercury enters and quite fills the thermometer. The open end is then drawn into a fine capillary tube, the mercury in the tube and stem being slightly heated; as it cools, the tube is finally sealed by fusing with a blowpipe the open end, and the thermometer is so far finished as to be ready for graduating. When very intense degrees of cold have to be ascertained, as mercury freezes at 40 degrees below the zero of Fahrenheit, spirits of wine coloured red is then used in a glass tube, as it does not freeze until a cold 68 degrees below zero exists. This fluid, however, would not do to measure heat, as it boils at 172 degrees, which is considerably less than the boiling-point of water, 212 degrees. To determine very high temperatures, as mercury boils at 680 degrees, various methods are adopted, all of which, however, are difficult of management.

We have in a former part of this work mentioned the expansion of iron by heat, and this is demonstrated in a very simple manner: *c a b* is a gauge into which the piece of iron *a* fixed to a handle, when cold, fits easily into the part cut out at the edge; but when *a* is heated, from its then expanded state, it will not pass into the open part: *f* is a circular rod of iron, and freely passes into the holes *b c* when cold; but on being heated, it is found then to be too large for the holes.

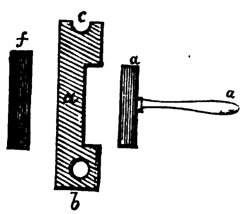


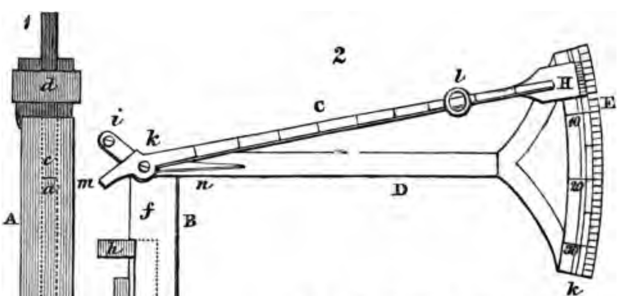
fig. 122.

Clay, as we intimated, contracts in proportion to the degree of heat. To measure these high temperatures, an ingenious contrivance called a *pyrometer* was invented by Mr. Wedgwood, the celebrated china-manufacturer; but hitherto none of these instruments can be said to be perfect. The best yet constructed, on which any dependence can be placed, is that by Professor Daniells, who thus describes his Register Pyrometer in his *Chemical Philosophy:* "It consists of two parts, which may be distinguished as the register and the scale. The register is a solid bar of black-lead earthenware, highly baked. In this a hole is drilled, into which a bar of any metal 6 inches long may be dropped, and which will then rest upon its solid end. A cylindrical piece of porcelain called the index is then placed upon the top of the bar, and confined in its place by a ring or strap of platinum passing round the top of the register, which is partly cut away at the top, and tightened by a wedge of porcelain. When such an arrangement is exposed to a high temperature, it is obvious that the expansion of the metallic bar will force the index forward to the amount of the excess of its expansion over that of the black-lead, and that, when again cooled, it will be left at the point of greatest elongation. What is now required is the measurement of the distance which the index has been thrust for-

ward from its first position ; and this, though in any case but small, may be effected with great precision by means of the scale.

This is independent of the register, and consists of two rules of brass accurately joined together at a right angle by their edges, and fitting square upon two sides of the black-lead bar. At one end of this double rule a small plate of glass projects at a right angle, which may be brought down upon the shoulder of the register, formed by the notch cut away for the reception of the index. A movable arm is attached upon this frame, turning at its fixed extremity upon a centre, and at its other carrying an arc of a circle whose radius is exactly 5 inches, accurately divided into degrees and thirds of a degree. Upon this arm, at the centre of the circle, another lighter arm is made to turn, one end of which carries a nonius with it, which moves upon the face of the arc, and subdivides the former graduation into minutes of a degree ; the other end crosses the centre, and terminates in an obtuse steel point, turned inwards at a right angle.

When an observation is to be made, a bar of platinum or malleable iron is placed in the cavity of the register; the index is to be pressed down upon it, and firmly fixed in its place by the platinum strap and porcelain wedge. The scale is then to be applied by carefully adjusting the brass rule to the sides of the register, and fixing it by pressing the crosspiece upon the shoulder, and placing the movable arm so that the steel point of the radius may drop into a small cavity made for its reception, and coinciding with the axis of the metallic bar. The minute of the degree must then be noted, which the nonius indicates upon the arc. A similar observation must be made after the register has been exposed to the increased temperature which it is designed to measure, and again cooled ; and it will be found that the nonius has been moved forward a considerable number of degrees or minutes. The scale of this pyrometer is readily



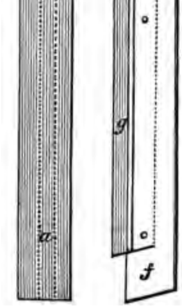


fig. 123. Daniells' Pyrometer.

connected with that of the thermometer by immersing the register in boiling mercury, whose temperature is as constant as that of boiling water, and has been accurately determined by the thermometer. The amount of expansion for a known number of degrees is thus determined, and the value of all other expansions may be considered as proportional.

1 represents the register : A is a bar of

black-lead; *a a* the cavity for the reception of the metal bar; *c* is the index, or cylindrical piece of porcelain; *d* the platinum band, with its wedge 1.

2 is the scale by which the expansion is measured: *ff* is the greater rule upon which the smaller *g* is fixed square; the projecting arm *h* is also fitted square to the ledge, under the platinum band *d*; D is the arm which carries the graduated arc of the circle fixed to the rule *ff*, and movable upon the centre *i*; C is the lighter bar fixed to the first, and moving upon the centre *k*; H is the nonius at one of its extremities, and *m* the steel point at the other. The rule *g* admits of adjustment upon *ff*, so that the arm *h* may be adjusted at the centre *i*, in order that at the commencement of an experiment the nonius may rest at the beginning of the scale."

The expansion and contraction of iron is exemplified in Hungerford Suspension Bridge, which crosses the Thames with a span of 1352 feet in length; the height of this chain roadway varies in the hottest day of summer and the coldest in winter to the extent of eight inches.

Due allowance has been made, in laying down railroads, for the expansion and contraction of the iron rails.

The steeple of Bow Church, in Cheapside, London, was fastened together with iron by the architect, and the consequence is, that the alternate expansion and contraction of the iron-work which take place on the changes of the temperature of the atmosphere have so loosened the masonry that the bells dare not be rung.

We know from every-day experience the effect produced by heat and cold on the strings of a pianoforte, the iron gates of a mansion, and the bell-wires of a house; we hear too, from the varying of the size of iron by temperature, of lamentable occurrences from the iron girders and pillars used in buildings bringing down the entire fabric by their change of length. Crystals will expand from heat in one axis, and contract in another direction. If the intimate composition of heated bodies be not changed, on the withdrawal of heat they assume their previous dimensions.

Often upon pouring hot water into glasses they crack, which arises from a great change in temperature being suddenly produced; this is more especially the case when the glass is thick, as then the change in temperature is more slowly communicated to the entire mass; thus thin glass may be suddenly heated and cooled with greater impunity than thick glass.

By breaking the cohesion of solids, their conducting power may be very much decreased; and on this account, by placing a layer of sand upon the hand, and carefully screening the surrounding parts, a red-hot ball of iron may be supported without inconvenience. At the siege of Gibraltar, red-hot balls were carried to the batteries in wooden wheelbarrows, merely protected with a covering of sand.

When our young readers may be amusing themselves by building a house of cards, they may at the same time exemplify the expansion of iron with a common knitting-needle. Let them rest one end of the needle against the house of cards, and place a paper-weight at the end resting *on the table;* then apply a lighted piece of paper or taper underneath the

needle, moving it along a small space near to the centre; upon doing so the needle expands, and will throw into confusion their frail building.

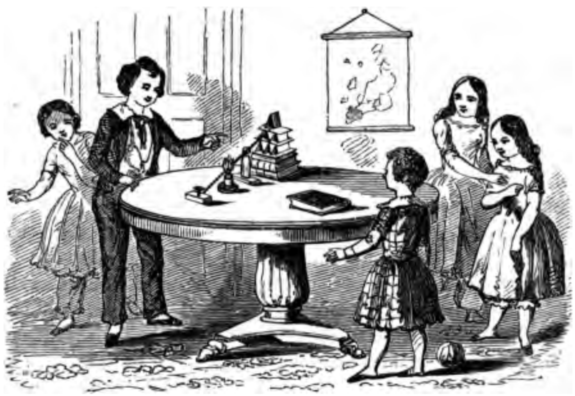


fig. 124.

The term *conduction* is used to express the diffusion of heat through a solid body. Did heat not spread slowly through the entire mass, even the poker could not be used to stir the fire without burning the hand that uses it.

That heat travels at different speeds through the structure of various substances is well known in the common experience of a teapot with a metal handle, and another with a wooden, bone, or ivory one, the former being hot when the latter is hardly warm.

Count Rumford made many interesting experiments on different substances, that he might ascertain the different degrees they possessed of the property of conducting heat, and they are ranked in the following succession: gold, silver, copper, platinum, iron, zinc, tin, lead, diamond, glass, marble, porcelain, clay, woods, fat or oil, snow, air, silk, wood-ashes, charcoal, lint, cotton, lamp-black, wool, raw silk, beaver's fur, eider-down, hare's fur.

If some article made of fur be lying on a marble table, both under the same circumstances will be of the same temperature ; but if we lay one hand on the fur and the other on the table, we shall say the one is warm, the other is cold : this arises from the marble being a better conductor of heat, which abstracting the warmth of the hand, gives a feeling of cold ; whereas the fur being a slow conductor, the heat of the hand does not readily pass into it but accumulates, and warmth is felt. If both the fur and marble be heated, then the hand would feel the heat pass rapidly from the marble, while the fur would scarcely feel any warmer than usual. Count Rumford considered gases almost non-conductors of heat, most especially when its particles are not allowed to move about, as is exemplified in sponge and other porous bodies containing a quantity of air.

In the foregoing list it will be seen how wonderfully nature provides for the preservation of animal bodies. The ostrich has light thin feathers, as

a spare clothing is only requisite for its warmth, while the sea-fowls have thick strong feathers and down to bear the rigours of the ocean's cold; the elephant has a few straggling hairs, while the arctic bear has a rough, thick, shaggy coat. The warm-blooded milk-giving whale is encased with fat to preserve its heat; and vegetation, in its bark, has a substance that is a slow conductor to heat, so that vegetable warmth is preserved without injury. Thus is every thing adapted by a superior wisdom to the circumstances of its nature.

The boilers of steam-engines are encased in materials to prevent the escape of heat by having a slowly-conducting covering exposed to the atmosphere; and in winter people wrap stable-straw around their water-pipes to prevent the escape of heat.

In the ice-shops of London huge lumps may be seen wrapped in flannel, by which the heat is prevented penetrating; and the chests sold for its summer preservation are made double, and the interstices filled with sawdust or fine charcoal. Man wraps himself in woollen cloths in winter, not because there is warmth in the wool itself, but that it is a slow conductor of heat, and therefore retains the natural warmth of the human body; for the same reason he uses blankets on his bed; nevertheless, a sheet of brown paper would answer his purpose equally well, if not better.

In domestic utensils many are joined together with solder. Now it is seen in the manufacture of them, that solder is rendered fluid by no very great heat; yet when exposed to an intense fire it does not melt, because the heat passes into the water, which never can be heated beyond 212 degrees; but if this material that conducts the heat away be dried up, then the solder melts. In some cases of local inflammation, medical men enfold the part in linen, not cotton, as the former is a conductor of heat, while the latter would, by not being a good conductor, retain the heat of the part already too hot.

To exemplify the difference between metal and glass in their powers of conducting heat, a simple experiment is exhibited. A piece of metal *b* and a piece of glass *d* of equal size and length are bound together at *c* with wire, and placed over a spirit-lamp *a*; and a piece of wax being placed on each of the other ends, that on the end of the metal *b* will be melted, while that on the glass *d* will not be softened.

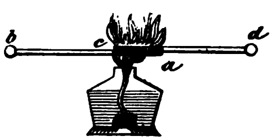


fig. 125.

Thus, from the difference of the conducting powers of heat in various bodies, we find brass cannon become hot sooner than iron; that water will boil in a metal pan quicker than an earthenware pipkin; and the emigrants to hot countries find a log hut and a thatched roof cooler in summer and warmer in winter than a brick or stone mansion. Snow being a bad conductor of heat, the inhabitants of the arctic regions build their huts of it for their winter residence.

There are other very neat modes of exhibiting the same results: as, for instance, placing a series of short flat bars of different metals of equal thickness and width on a circular piece of wood like the horizon of a globe, having the points all meeting in a centre, underneath which is a spirit-lamp, the

flame equally touching the points; near and on the further ends is placed a very small piece of phosphorus. When the heat begins to act on the metals, the phosphorus on the gold first flashes into flame and smoke; and nearly at the same time, but still not till after the gold, that on the silver; after a short space that on the copper, then follows the platinum, after that the iron, and then the lead.

Sometimes small pieces of wire of different metals are fixed at one end into a slip of wood and tipped with candle-wax, and the other ends of the wire are then placed in a trough of heated water at exactly the same depths; the wax is seen to melt first on the silver, gold, and then at short intervals on the other metals.

Again, the ends of the wire are made to protrude through the wood, and a marble fixed by wax on the other end; this last end is placed so as to hang over a table or box, and a heated bar of iron being brought against the short end projecting through the wood, first the marble attached to the silver wire drops, then that to the gold, followed by that on the copper, platinum, iron, and lead.

If in the experiments with the phosphorus and marble a piece of glass be used along with the metals, the phosphorus would not fire, nor would the marble drop, as before the heat could arrive at the ends, the bar of iron would become cold.

Count Rumford's experiments led him to believe that there could be no change of temperature in liquids without a displacement of their particles, which differs in respect to solids, and in this case is called convection. When under a vessel of water A A, heat is generated by a lamp B, the portion near the bottom is dilated, and rendered specifically lighter; which ascends, and the colder and denser particles sink down to their place, and in their turn ascend. A continued current is thus created, the heated particles rising in the centre, as at C C, and the colder ones descending at the sides, as represented by the arrows D D: by thus constantly changing the particles, the heat is spread over the mass of water, and the whole is sooner at the boiling-point than the same could by conduction be made to pass into a solid. There is a popular experiment shewn by lecturers on this branch of science to prove that water is a bad conductor of heat; this consists in having a hollow tube, at the bottom of which is placed a piece of ice, kept in its position by a small weight, and the rest filled up with water; the tube being held slantingly, a spirit-lamp is applied near the top, when the water in that part is made to boil, while the ice remains unmelted.

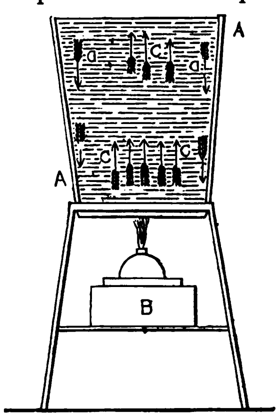


fig. 126.

If a piece of paper be wrapped around a piece of wood, and passed slowly through a flame, it will be speedily consumed in comparison to a similar roll of paper around a bar of iron; this arises from the wood less greedily absorbing the heat than the iron, consequently there is more

heat left to consume the paper around the wood than that around the metal.

Air when heated ascends or moves away; causing the colder air to rush in, producing the delightful variations of warm and cooling breezes, and, in fact, the circulatory movement of the whole atmosphere, which brings with it a softening influence over the less heated parts of the globe in the unceasing endeavour of the whole to become of an equalised temperature. If a lump of ice be introduced into an apartment, the air in immediate contact with it becomes denser and sinks, other air rushes to supply its place, and ultimately the particles of heat in the continually renewed air melts the ice. If a tube be nearly filled with water, and a lamp applied, as shewn in fig. 127, the water at the upper part would boil, whilst that at the bottom would remain cold as at first. It may be inferred, then, that were the atmosphere heated at its surface, as the water in the tube, there would be no equality of temperature, by which both the Torrid and the Arctic Regions are rendered habitable; but as the heat proceeds from the bottom of the aerial ocean, it is warmed as the water described in the vessel, by upward currents, as exemplified in fig. 126. Now it is plain the waters of the globe cannot be heated by convection but by conduction, which is so slowly accomplished that deep waters always remain cool. When frost descends on the watery fluid of the earth, it causes the surface to be cooled and dense, then sink to the bottom, and forces up warmer water to its place; this in its turn sinks; and this system of carrying or convection keeps up a circulation until the whole mass from top to bottom has increased in density and occupies less space. Were the water to reach 32 degrees of cold, it would begin to freeze at the bottom; but, by a wise provision of Providence, when the surface-water is about 39½ degrees of temperature, the usual operations of nature seem to change; it begins to expand and have less density, and ice forms a crust over the surface, protecting the fluid underneath from the frigidity of the atmosphere, actually warming the lower water, and preserving the lives of the living creatures underneath. From the whole mass of water throughout having to become dense before the process of ice formation commences, the deep seas of cold climates are not frozen, or the lakes that rest in deep basins. The cooling of the water by the giving out heat that it contains, has the effect by the lost warmth of adding it to the surrounding atmosphere, which accounts for inland parts of countries being colder than those parts near the sea, even when in a warmer latitude. In summer the humid breeze of the ocean preserves on its shores a cooler atmosphere than is enjoyed by inland parts. Thus the coasts of Scotland and Ireland have neither the heat of summer nor the cold of winter felt by the denizens of the British metropolis. This is from the breezes in winter coming from over the ocean, which, not being frozen, is warmer than the land; and in summer, the sea not being so heated as the land, the breezes are cooler. Frost in England penetrates but a few inches below the surface; and hence, in all

fig. 127.

parts of the world, at a little depth below the surface the temperature is about the same: by this grand ordination the life of the vegetable kingdom is preserved.

All substances absorb heat to which they are exposed in a more extended or lessened degree, the power to do so varying in different bodies. Thus, then, when bodies are exposed to the sun, in a given time one may absorb a considerable quantity of heat, and another very little. This is plainly demonstrated by an instrument called a differential thermometer, used to observe the laws of radiant heat. It consists of two tubes placed perpendicularly, having bulbs at the top resting against graduated scales; but the tubes are continued horizontally, so that they become as it were but one bent tube with bulbs at the extremities. Into the tube is put some coloured sulphuric acid: the bulbs being full of air, when the temperature is equal in both bulbs the acid is of course the same height on both sides of the tube; but when one bulb is exposed to heat, then the air in that bulb expands, and pressing upon the liquid, drives it up the other side of the tube, being then highest in the coolest tube. The difference of temperature is then observed on the graduated scale, and the degree of heat thus measured ascertained.

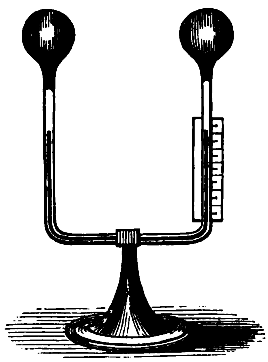


fig. 128.

This thermometer shews in an admirable manner that the power of absorption depends mainly on the nature of the surface; for if both bulbs be exposed to the same degree of heat, and one have a coating of lamp-black, while the other is in its natural condition, a considerable difference in temperature will be observed; and by covering one of the bulbs with any particular substance or colour, the powers of absorption may be ascertained. By this means a bright metallic substance spread over a bulb has been found nearly to destroy the powers of absorption, and even the heat of the room, while black paper or cloth increases it to a great degree.

A black coat is the warmest covering in summer and the coldest in winter. In summer the body is cooler than the external atmosphere; and a black coat, absorbing the heat, raises the temperature of the body; in winter the body is warmer than the atmosphere, and then the black cloth radiates the heat from the body.

The shaggy coats of the Polar bears are white, so as not to radiate the heat of the body of the animal, and enable them to sustain the rigours of the intense cold.

The sailors who have been sent on the various Arctic expeditions are provided with clothing of a kind of sky-blue or French-grey colour, as one of the best to preserve the heat of the body from being radiated, consistent with a tint sufficient to render them distinguishable on the white ground, and prevent them being mistaken for bears on two legs, which their muffled uncouth appearance might lead some of the nautical hunters to imagine.

We have known a curious experiment made by an ingenious youth to arrive at some knowledge of the absorbing powers of heat by coloured

bodies; this consisted in providing a number of small bags of various coloured cloths. In each was placed a very small piece of phosphorus; they were then hung from a circular hoop over a plate of iron kept heated by a fire beneath, and gently and gradually lowered. On the first explosion in the black bag taking place, the height of the thermometer, which was suspended in the centre the same height as the bags, was carefully noted down; and this mode continued until the phosphorus in the white one was ignited. This youthful device was certainly illustrative of an inventive mind; and shews, where it is bent on a particular object, and the usual means of demonstration not at command, the ingenious methods that will spring up to satisfy the cravings of genius.

Colours, then, possess different properties of absorbing heat; and Dr. Franklin, by experiment, found those which absorbed most light absorbed most heat. He laid pieces of different coloured cloth on snow, and watched them for a time while the sun was shining upon them, noting the different depths to which they sank by the melting of the snow underneath.

The rays of heat that pass into a body are not entirely absorbed, but will pass through, only leaving each time a portion of their property, until the gradual warming is equal to the powers of the rays. If the body be thick enough, the rays are absorbed; but if not, they pass through and continue their course.

When heat is transmitted through the air, and comes from bodies in rays, it is then termed *radiant* heat.

If a red-hot cannon-ball A be suspended by the wire E, heat will be found to radiate from it in all directions, the intensity of the rays diminishing in regular proportion to the distance; thus at three feet, as at *b*, there is nine times less heat than at one foot *a*; sixteen times less at four feet *c*, and twenty-five times less at five feet *d*. These rays are instantaneously diffused and given out in straight lines; but, like light in some transparent substances, they are bent or refracted. When the rays are stopped and swallowed up or absorbed, then the body so doing is increased in temperature. It passes best through the worst conductors, air and gases; while metals arrest its progress, and if polished, reflect it. Heat resembles light in its swiftness, and accompanies it in the sunbeam, but can be separated from it and concentrated, as was done by Archimedes when he burnt the Roman fleet. It differs from light in its focus, and does not heat the air through which it passes; and, like light, the most boisterous winds do not move it from its course.

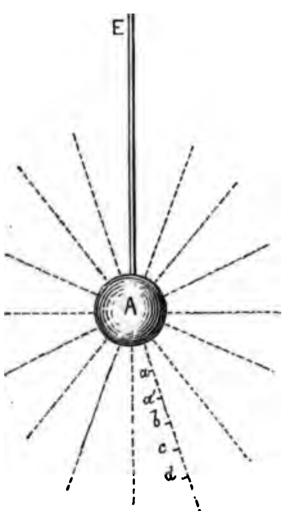


fig. 129.

Inequality of temperature exists among objects exposed to the same degree of heat, from the various properties they possess of absorbing and parting with heat, which depends on their conducting powers and the state of their surfaces; and it is singular that the absorbing and radiating powers

are nearly proportional. If the radiating power of lamp-black be 100, writing-paper is 98, sealing-wax 95, crown glass 90, ice 87, plumbago and isinglass 75, tarnished lead 45, mercury 20, clean lead 19, polished iron 15, tin-plate, gold, silver, copper, and tin polished 12. Thus a vessel covered with lamp-black will cool down hot water in half the time to what it would if it had a polished surface; but water in a polished vessel may be quickened in its cooling by enveloping it in thin cotton or woollen cloth. This may arise from exposing to the atmosphere a larger surface, as a roughened one both receives and gives out heat more rapidly than a smooth one. There is this difference between the heat from the sun and that produced by artificial means, as from a fire; the first darts through air, glass, water, and other bodies, whereas the latter is arrested in its progress. We have stated that the rays of the sun pass through the air without leaving much of the property of heat; they fall on the surface of the earth, and by convection the atmosphere is heated. But all the rays of heat do not pass into the earth, for some are reflected; and according to the angle of incidence is the angle of reflection.

The apparatus for concentrating and shewing the effects of the radiation of heat consists of two metal mirrors highly polished. These have the form called paraboloid; and any number of rays coming from their focus are reflected into parallel directions, which coming to such another

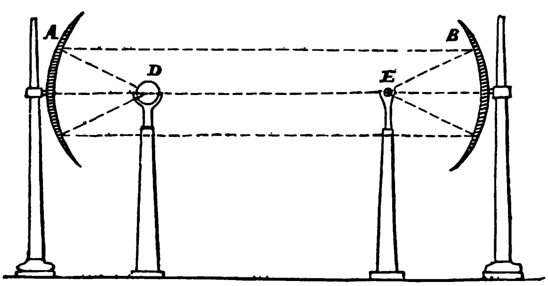


fig. 130.

mirror, are all reflected so as to meet in its focus. A B are the two concave mirrors placed exactly opposite each other, so that all the rays of light or heat issuing from the focus of one may be collected in the focus of the other. If a red-hot ball be placed at D in the focus of A, the rays passing from the ball to A will be reflected in parallel lines to B, and reflected from it to meet in its focus E. Now if gunpowder, phosphorus, charcoal, or paper be placed at the focus E, they will be fired or burnt; and if a thermometer be within the influence of the focus E, it will be more affected than if near to the heated ball. If a piece of ice be substituted for the hot iron, the mercury in the thermometer will fall. This made many persons think that cold had a positive existence, which was an error, as cold is a mere sensation from the lessening of heat. In this case the hot ball radiates heat in all directions; and the rays that act on the thermometer are only those that fall on the surface of the reflector, from the part of the ball opposite to it. If the thermometer be held out of the

focal point, or in any part intercepting the heat-rays, a change of temperature will hardly be perceptible. The thermometer having the heat of the room in which it is placed when subjected to the piece of ice, is then the hot body, and radiates its heat to the ice; consequently its temperature falls in proportion as it may be above that of the ice. Hence it is not rays of cold, as many suppose, that affect the thermometer, but the radiation of heat from it to the ice.

When the face of one of these mirrors is turned directly opposite to the sun, the focus has the power of burning with intensity; but if turned to the zenith of a clear blue sky, the thermometer presented to its focus sinks considerably: this arises from the mirror intercepting the heat which would reach it from the earth, and the absence of clouds to reflect back the heat; but when clouds intervene, the thermometer rises at once. This teaches us that every thing on the earth is radiating heat, and that the clouds in the heavens perform the same office. When the sun passes from our view to distribute its glorious favours to other lands, the radiation of heat still goes unceasingly on; and the earth's surface, which in the day was warmer than the superincumbent atmosphere, parts with much of its heat; and the moisture held in the air is condensed, forming those pure and sparkling globular gems that bedeck every leaflet and blade of grass, which we name *dew.*

When the sky is cloudy there is little or no dew, as the heat radiated from the earth is sent back from the clouds. The moisture of the atmosphere being lessened, and so much heat liberated by the formation of dew, the air is consequently warmer. Gardeners, to prevent dew falling on some parts, cover them at a short distance from the earth with calico or other thin material, and thus arrest the free radiation of heat from the surface. The pearly drops that imperceptibly form on vegetation are but scarce on rocks and barren earth, arising from these bodies being bad radiators of heat. The cooling of the atmosphere, then, is the reason of the formation of dew, and this is termed the dew-point; the difference between the temperature of the dew-point and that of the atmosphere shews the dryness of the air; and it is found by means of an instrument called a hygrometer. The beneficent provision of dew, and the wonderful laws by which it is regulated, evince the great intelligence reigning throughout the universe. Moses speaks of it as one of "the precious things of heaven."

After being participators of a "gay and festive scene," on coming into the open air, and seeing presented to our eyes a serene and cloudless sky bespangled with the little wondrous orbs of intense brilliancy, how often does the expression escape our lips, "What a lovely, delightful night for a walk!" while, on the contrary, we feel dubious and alarmed if clouds curtain the glories of the blue vault, and seek to defend our persons by extra clothing. Now the very opposite ought to be our conduct: on the cloudless night the heat is radiated from the earth and passes off into space, creating a degree of cold that may strike the delicate and unprotected in such a manner as to result in consequences of the most fatal nature; whereas, when clouds hover above us, they radiate heat, and prevent the earth becoming so cold as in the case previously mentioned, and therefore there is a nearer approximation to the heat of our bodies, and

lessened danger. This is exemplified on taking open-air exercise at a period when rain is about to fall, as we feel a sense of closeness which is productive of perspiration.

On the wind moving about the particles of air we feel the sensation of cold, from the heat generated by our bodies being driven off; while, on there being no wind, our bodies warm the adjacent air, which not being immediately carried away and replaced by colder air, we feel a greater degree of warmth. Thus on there being wind, although there may be no ice, the cold will be more keenly felt than when the thermometer is much lower and no wind. Hence a thaw frequently feels colder than a frost, there being an absence of dry wind.

Almost every body in nature is susceptible of three several states of existence, solid, liquid, and aeriform; and these conditions depend on the quantity of caloric or heat they contain. Thus water may be in the state of ice, water, or steam; mercury may be as a solid bar, liquid, and as gas. At the ordinary heat of the atmosphere some objects are solid, as metals and stones; some liquid, as water and oils; others are air, as nitrogen and hydrogen. This is dependent on their relation or affinity to heat.

Oxygen, that possesses an immense affinity for heat, and exists as a gas, may be combined to a solid, as in the case of the rust of iron. But without this combination, Dr. Faraday, by compression and cold, has both liquefied and solidified many gases. The application of heat to solids has the effect of first expanding their bulk; some become softened, and others at once pass from the solid to the liquid, and then, on continuing the heat, to the gaseous form; while some pass from the solid to the gaseous without becoming liquid. To a certain point some solids will receive heat and preserve their conditions, but beyond that point will change. It is a singular fact, that what is called the melting or freezing point is always exactly the same in the same substances; thus ice melts, or water freezes, at 32 degrees on Fahrenheit's scale. The freezing-point of mercury is 40 degrees below zero. If ice be placed before or on a fire, and a thermometer be placed in it, and if the temperature of the ice be at zero, it will rise as it begins to melt to 32 degrees, and there will remain for a short time; but will then rise to 40 degrees, as high as the lower surface of the ice, but above that it will be about 32 degrees; the heat, therefore, effects fluidity, but does not increase temperature. Though a vast body of heat appears lost in this process, yet in restoring the water again to ice, the whole is recoverable. Water and mercury placed side by side on a hot plate require different periods to arrive at the same state of heat. In fact, the water will require thirty times as much heat as the mercury; and if both substances be used to melt ice, the water will do so to thirty times as much as the mercury; and if an equal weight of hot water and cold mercury be mixed, the water will heat the mercury thirty degrees; whereas, if the conditions be reversed, the water cold and the mercury hot, the last body will lose thirty degrees of heat in equalising the temperature. Water, under the ordinary pressure of the atmosphere, boils when it has a temperature of 212 degrees, and no increase of heat will raise it above that point. These circumstances of susceptibility to heat in equal weights of different bodies are termed their capacities for heat. A very simple experiment may afford a rough estimate of the comparative powers of conduction in the three classes of solid, liquid, and gaseous bodies. Metals

heated to 120° will severely burn a hand placed upon them, owing to the facility with which the heat will travel towards it; water will not scald, provided the hand be kept without motion in it, till it reaches the temperature of 150°, while the contact of air may be endured at 300°. Sir Joseph Banks ventured into a room heated to 260°, and remained there a considerable time without inconvenience; and in several processes of the arts it is necessary for workmen to enter stoves heated as high as 300°, from which no injurious effects follow.

To know the expansion of solids from heat, the pyrometer is applied; and the amount of increase of length is found to be one-third of the increase of its bulk in breadth and depth; from this rule, therefore, the total enlargement may be ascertained.

We have remarked, that when ice was melting a quantity of heat disappeared and seemed to be absorbed, the heat only effecting fluidity, not increase of temperature; and this is applicable to other solids as well as to ice. The heat thus lost, when being converted into a liquid or a gas, is called *hidden* or *latent heat;* and its discovery is owing to the researches of Dr. Black, who found that whatever time was necessary to heat the ice one degree, exactly one hundred and forty times as much would be required for melting it, thus that 140 degrees is the latent heat of water; and Lavoisier, a celebrated French chemist, invented a heat-measure or calorimeter, which consisted of a vessel lined with ice; and the quantity of heat given out by any body placed in it is indicated by the quantity of water collected from the melted ice.

The calorimeter is made of tin or iron plates A A, and inside is a smaller one B B, in which is a wire vessel C, to hold the substance that is to be tested. Between the first and second vessels, as also between the second and the wire cage, the space is filled up with pounded ice. The ice between A and B prevents the warmth of the atmosphere acting on the enclosed substance; thus the ice around the wire vessel is affected only by the heat from the substance examined, which melts the ice until its temperature reaches 32 degrees. The ice thawed by the substance runs off as water at the cock D, and is afterwards weighed. As melting ice is always at 32 degrees, all the heat applied goes to thawing the ice; and therefore as to the quantity melted so is the amount of heat expended. A pound of water 135 degrees above freezing-point will melt 1 lb. of ice.

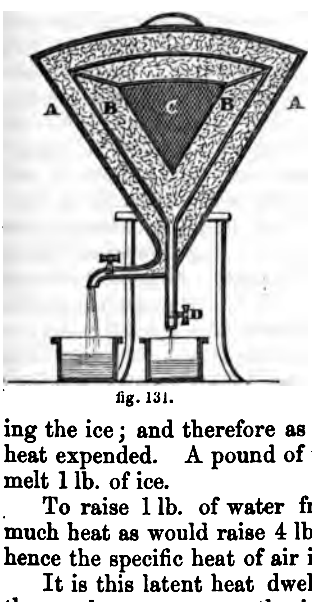


fig. 131.

To raise 1 lb. of water from 32 degrees to 212 degrees requires as much heat as would raise 4 lbs. of atmospheric air to that degree of heat; hence the specific heat of air is one-fourth that of water.

It is this latent heat dwelling in bodies that prevents the freezing of the earth or ocean, or the instantaneous conversion of snow into water, and allows the changes to be gradual and foreseen. Metals slowly melt or become hard from the same cause. It is now found that in bodies pass-

ing from the solid to the liquid state, they absorb and keep within themselves certain quantities of heat termed latent; for example, ice holds 140 degrees, mercury 142, bees'-wax 170, tin 442, zinc 492. The latent heat of the steam of water is 1000 degrees, that of vinegar is 900 degrees, alcohol 442, ether 300, and oil of turpentine 177. Latent heat is beautifully illustrated in the slaking of hot lime; the water poured upon it becomes solidly combined with the lime, while the latent heat is liberated from the chemical action that takes place. The heat given out by steam-pipes is the latent heat contained in the steam which is condensing into water.

The sun is the great source of heat; though some heat is thought to proceed from the centre of the earth, as the deeper we go the increase is found to be for every foot one degree, beginning at 50 feet below the surface, as a uniform temperature which is found all over the world. Of what the glorious and life-giving sun, which the enthusiastic but erring Persian worships as the governing deity, is composed, is a matter philosophers have not yet been able to decide. Some think it an intensely heated mass, while others assert that it may produce its effects without waste of its own body, and that it is possible beneath its luminous atmosphere animated nature exists as on this earth. It is thought that heat and light is merely motion in the ether of space, similar to sound in the air, producing the phenomenon of which we are sensible, and ought to be grateful for the blessing. As yet this mystery is hidden from the grasp of man's intellect, and he can only wonder at and adore the wisdom and benevolence of God.

There are several curious phenomena connected with the subject of heat; the best known is, that when having left water until the fluid is in a freezing condition, and as a consequence increases in bulk, the strong iron pipes in which the water for the supply of towns is contained burst from the force exerted. An experiment was made of putting a little water into a bomb-shell and retaining it there by an iron plug of three pounds weight; the water being afterwards frozen, the plug was shot out to a distance of 415 feet. We have previously noticed that water thrown into a red-hot crucible assumes a spherical shape, is repulsed, and does not evaporate until the temperature is lowered, when it comes in contact with the vessel, and then suddenly bursts into vapour. It would seem that dry steam keeps the rolling globules from the vessel, and the water is several degrees below the boiling-point. The visitors to the Polytechnic Institution were astonished to see the experiment of M. Boutigny, who froze water in a red-hot crucible. This was accomplished by pouring into a heated platinum crucible some sulphurous acid, perfectly destitute of water, and then an equal bulk of water. The acid immediately evaporated, withdrawing so much of the sensible heat of the water and crucible, and rendering it latent, as to reduce both in temperature below the freezing-point, and thus convert the water into ice, so that a solid lump from the hot crucible was laid before the wondering audience.

Professor Faraday froze mercury, by placing in a hot crucible solid carbonic acid and ether, then pouring in the mercury.

When a stream of the vapour of carbonic acid, under a pressure of fifty or sixty atmospheres, is allowed to pass into a box made in a peculiar manner, in which there are winding passages for the vapour to pass

through before it can escape into the air, a snow is produced that may be worked in the hand like a snow-ball, producing no other effects than would take place with real snow, and it may even be placed in the mouth without any harm resulting; but if put into sulphuric ether, or any other uncongealable substance, the consequences are as dangerous as dipping the hand into liquid iron.

At a lecture at the Royal Adelaide Gallery we remember seeing the lecturer freeze mercury 95 degrees below zero. The lump of solid metal, when laid at one side, seemed to draw to itself all the heat of the apartment, a chill was felt, the invisible vapour ran down the walls, and ladies drew around them their shawls and cloaks, looking about to see from whence proceeded the disagreeable draught that they imagined was pouring into the room. On applying this solid piece of mercury to a candle, with such avidity did it absorb the heat, that the light was almost instantly extinguished. The frozen lump was then beaten with a hammer in the same manner as heated iron is operated upon by a blacksmith, and occasionally was dipped into the freezing solution as iron is replaced in the forge, and at length was seen as a thin sheet of solid mercury. A gentleman had the imprudence to place the solid lump in the palm of his hand, and on instantly reversing it, to allow the mercury to drop, it seemed for a few moments to adhere, creating a sore exactly the same as if molten lead had been poured upon the hand, but of such difficulty in healing, that some months elapsed before a cure was effected.

A sailor at the North Pole having to convey a bottle of brandy from one tent to another, placed one of his fingers in the neck as a cork, when on arriving at the tent where he had to convey the brandy, he found his finger frozen to the bottle, and it had to be disengaged by breaking the neck into small pieces. His finger was found to be frost-bitten.

In our remarks on dew we stated that the nature of the surface influenced its production: this fact was beautifully illustrated in those clever experiments named Möser's Figures, and has led to the art termed *Thermography*. A coin was placed on a looking-glass or other glass backed with tinfoil, and a few sparks of electricity directed upon the coin from the prime conductor of a machine. On sharply removing the coin and gently breathing on the part where it had lain, an outline impression was seen pencilled in the moisture of the breath. There might be a pile of glass and coins with similar results of each. Iodine or mercury likewise makes them visible. If a silver coin be left on a glass and exposed to the rays of the sun, then the part be breathed upon, the same phenomenon may be observed. Breathe on a clean pane of glass uniformly, then write upon it with almost any material, let the glass dry, and each time that it is breathed on afterwards the writing will be visible.

Mr. Hunt shewed the same effect by gently heating a coin and placing it on polished silver. In the experiments of Mr. Hunt, he found that if a gold, silver, and copper coin were placed on polished copper gently warmed, and then cooled and removed, there were excellent representations of the gold and silver coin on passing the plate of copper over the vapour of mercury, but hardly any of the copper coin; it thus became apparent that the two materials of the coin and the plate must be different. If a smooth clean plate of copper be given a bright surface by rubbing it with nitrate of mercury, then a sheet of printed paper be placed upon it,

the printed part against the polished surface, and pressed by having several folds of paper and a weight above it; this to be next placed on a warm substance so as to gently heat the whole for half an hour, in which time the radiation of heat from the printer's ink marks the polished surface, but is not visible until being exposed to the vapour of mercury, which adheres to the parts corresponding to blank parts of the paper, and then to the vapour of iodine, which blackens the parts against which the impression of the types was pressed,—the whole appears as a beautifully printed page, an exact transcript of the original.

As in experiments on the refraction of light, glass prisms and lenses are always used, so in experiments on heat are prisms and lenses made of rock-salt always employed, as being the best medium for allowing the free passage of heat, and is therefore termed diathermanous. A convex lens of clear rock-salt brings radiant heat to a focus, and thus is known the intensity either in boiling water, fire, light, or any other substance; and if heat be thrown through a rock-salt prism, its rays are separated into an invisible spectrum, and it transmits more than 90 per cent of incident heat, rendering it to the latter what glass is to light.

As light and sound move in waves, so does radiant heat; but the waves of heat are larger than those of light, being about thrice as long as the red waves, and four and a half times as long as the violet waves of light; thus, then, heat from the sun moves not with the same velocity as light, being only four-fifths, or about 163,600 miles in a second.

By an instrument named the Jachopyrion, or atmospheric tinder-box, tinder and other easily inflammable substances are ignited, from the rapid condensation of air. It is made of glass or brass, about 10 inches long, hollow, and very small in the diameter. A piston *a a c c*, attached to a rod *b*, works in the tube *e* and fits very exactly; in a hollow *d* on the lower part of the piston is fixed the tinder, and on the operator driving it suddenly down to the bottom, ignition takes place.

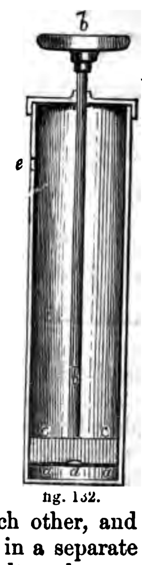


fig. 132.

When we desire to warm any thing with our breath, we open the mouth and send the stream of warm air from the lungs slowly and gently; but if we want to cool a hot substance, we contract the muscles of the chest, narrow the mouth to a small aperture, and blow quickly and strongly. If air be compressed into a cylinder vessel with the weight of three atmospheres, and then allowed to escape through a very small hole, the heat rendered latent by the air in its expansion as it passes out will be such as to freeze water.

Every-day experience teaches us that a little air passing through a crevice is colder than the surrounding atmosphere.

When snow and salt are mixed they mutually liquefy each other, and a greater degree of cold is felt than in either of the bodies in a separate condition, which arises from the sensible heat both of the salt and snow becoming latent during liquefaction; the glass or other vessel holding the mixture also loses part of its heat, and the more rapid the liquefaction the more intense the cold. Not only does this take place in salt and snow, but also in other crystalline substances that are capable of mutually liquefying

each other: this has been turned to account for the production, in hot weather and in hot climes, of the luxury of iced drinks. The mode adopted by Mr. Walker consisted in having broad tin cylinders with thick sides, in which were enclosed two cylinders, one within the other, with thin sides of the same height as the outer one, and fastened together at the bottom. In the innermost cylinder, and in the space between the first and second, was placed a freezing mixture, consisting of 5 parts of chloride of ammonia, 5 parts of nitrate of potassa, and 10 parts of water at a temperature of 50 degrees; the substance to be frozen was then put into the space between the second and third cylinder, and the cold produced by the mixture lowering the temperature to 10 degrees, the water or other substance last put in is rendered a solid piece of ice.

By mixing solid carbonic acid with sulphuric ether, alcohol has been made to have the consistency of oil, and the resemblance of melted butter.

Water if kept perfectly still, and having a little oil swimming upon it, will become as cold as 10 degrees Fahrenheit; but if disturbed, the formation of ice commences, and the temperature rises to 32 degrees.

People bathe in summer that their pores may be opened, and the heat of their bodies more readily pass off into the atmosphere; as the cool of evening approaches they feel the luxury of participating in the temperature around them. On rising from their bath the evaporation of the water from their bodies carries off with it a portion of the heat, and thus they feel cold. On this principle are wet cloths wrapped round bottles of wine. This is a common mode of cooling wine on board ship. The bottle is at the same time suspended from some portion of the rigging to hasten the evaporation.

Water may be frozen by evaporation, as was exemplified in the following experiment by Leslie. He placed a thin metal cup *a* on a tripod-stand *b b*, and put it into water; and a dish about two inches distant underneath, *c*, he filled with concentrated sulphuric acid to within half an inch. This apparatus being on the plate of an air-pump, and covered by a glass *d d*, on the air being exhausted the vapour of the water rises to fill the vacuum; but as sulphuric acid has a powerful affinity for water, it absorbs the vapour as fast as it is formed, thus producing a very quick evaporation; and the latent heat being carried off by the vapour of the water, the remainder of the water is frozen.

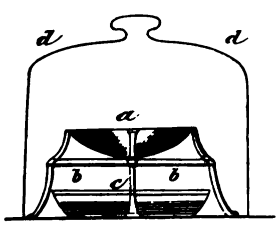


fig. 133.

The heat from the rays of the sun is increased the nearer the body is placed at right angles. A knowledge of this has led to an improvement in the growing of wall-fruit, a slanting roof instead of a perpendicular wall being found to answer best; and the greater the opacity and the rougher the surface, the more is the heat increased.

The last phenomenon we will notice is that exemplified in Trevelyan's instrument, the Thermophon. This consists of a heated metallic body, usually brass, being laid on a cold block of lead, which it gradually heats; and during the process of cooling, as the brass contracts by regular pulsations, musical sounds strike the ear, and continue until the heat of the two metals are equal.

In conclusion, we may observe that heat is derived from many sources:

mechanically by pressure, percussion, and friction; from the essential principle of organic life being a little above 90 degrees in the human body, and 100 degrees in many animals, 120 in birds, and generally greatest in the smallest; from electricity, chemical action, the rays of the sun, and from the earth itself. Terrestrial heat is accounted for by many learned geologists in this manner: they state that, in their belief, the earth at one time was in a hot, fluid state; gradually the crust cooled, fitting it as a place for the habitation of man and beast; that its centre is in process of cooling, and as proof of its internal heat we have volcanoes, hot springs, and increase of temperature in deep mines; that this central heat is gradually diminishing, and effecting a change on the superficial temperature.

Davy remarks: "The immediate cause of the phenomena of heat, then, is motion; and the laws of its communication are precisely the same as the laws of the communication of motion. Since all matter may be made to fill a smaller volume by cooling, it is evident that the particles of matter must have space between them; and since every body can communicate the power of expansion to a body of a lower temperature, that is, can give an expansive motion to its particles, it is a probable inference that its own particles are possessed of a motion; but as there is no change in the position of its parts as long as its temperature is uniform, the motion, if it exists, must be a vibratory or undulatory motion, or a motion of particles round their axes, or a motion of particles round each other. Again, it seems possible to account for all the phenomena of heat, if it be supposed that in solids the particles are in a state of vibratory motion, the particles of the hottest moving with the greatest velocity, and through the greatest space; that in liquids and elastic fluids, besides the vibratory motion, which must be conceived greatest in the last, the particles have a motion round their own axes, with different velocities, and separate from each other, penetrating through right lines. Temperature may be conceived to depend upon the velocities of the vibrations, increase of capacity on the motion being performed in greater space; and the diminution of temperature during the conversion of solids into fluids or gases may be explained on the idea of the loss of vibratory motion, in consequence of the revolution of particles round their axes, at the moment when the body becomes liquid or uniform; or from the loss of rapidity of vibration in consequence of the motion of the particles through greater space."

OPTICS.—LIGHT.

THAT branch of science which treats of the nature and laws of vision is called *optics;* and as it is by the medium of *light* that objects become visible, the two subjects naturally become blended, and form most interesting themes of scientific inquiry.

The science of optics is usually divided into three sections: the first denominated perspective, which treats of the apparent size of objects from the laws of straight-lined motion of light; the second is called catoptrics, signifying to see from or against, embodying the law of reflection of light from surfaces; the third division is named dioptrics, meaning to see

through, which refers to the laws of refraction, that is, when light is passing through a transparent body, the bending that the rays undergo.

Light, like heat, cannot be defined. Some suppose it to be an undulation or vibration caused by luminous bodies on the medium between the object and our organ of sight, which vibration we call light; this view of the subject is called the undulatory theory. Others suppose light to consist of inconceivably small particles of matter thrown off from a luminous body with prodigious velocity in all directions; this is termed the theory of emission; but few now entertain this opinion.

Whatever light may be, it is found to penetrate through many solid transparent or translucent bodies, and not to have the smallest sensible weight.

Bodies are said to be luminous, opaque, and transparent. Luminous bodies are those which, within themselves, possess the property of exciting the sensation of light or vision, as the sun, the stars, electricity, the fire, the candle, hot iron, phosphorus, the glow-worm, and others. Some opaque or non-luminous bodies have the power of shining from a borrowed light, as a polished metal, the light received from a luminous body by it being reflected to others; but without this borrowed light it would be dark. Opaque bodies are, therefore, not self-luminous, and prevent light passing through them. Transparent bodies are those that have the property of allowing light to pass through them, as air, glass, water, &c. They are sometimes called mediums by which light is said to be transmitted. Strictly speaking, substances are only transparent through which light freely passes and objects can be distinctly seen, as in glass, horn, &c. The term translucent is applied to those that permit the light to pass freely through them, but through which bodies cannot be discerned, as ground-glass, paper, porcelain, &c.

The salts composed of metals or earths with acids, that constitute crystals, are generally transparent; but when crushed to powder, they are opaque. Metals which in thick masses are opaque, when in solution may be beautifully translucent; or when some are reduced to a thin leaf by the ingenuity of man, as is observable on decorated lamp-glasses. But air arrests a considerable portion of light as it passes through it; and water does not allow it to penetrate a depth beyond seven feet, without absorbing one-half of its quantity. Practised divers know that in the clearest water they soon find darkness as they descend, and that the bottom of the ocean is a world without light.

The rays of light under ordinary circumstances are emitted in direct lines, as proved by their not passing through a bent tube; also, as the substance on which they fall and the shadow form right lines with the ray. It was believed that the velocity of light was instantaneous, until astronomers discovered, in the eclipse of one of Jupiter's satellites, that the motion of light was progressive. They watched the satellite entering his shadow when that planet was nearest the earth, and found that the light reflected by it took about 33½ minutes in reaching us, and when farthest from it about 50 minutes; hence proving that the rays of light were 16½ minutes in travelling the diameter of the earth's orbit, or 8¼ minutes in passing from the sun to us, a distance of 95,000,000 miles. Multiply the 8¼ minutes by 60, to reduce them to seconds, and divide the distance by the seconds, and it will be found light has a velocity of about 192,000 miles in a second. This speed is nearly a million and a half times

quicker than a cannon-ball, which acquires a velocity of about eight miles in a minute.

When the moon is full, the mild and beautiful light it reflects amounts to about a hundred thousandth part of that of the great and powerful sun; its distance is ten times the earth's circumference, consequently scarcely a second and a half is occupied by light in its journey from the moon to the earth. From the planet Neptune, recently discovered by a triumphant achievement of science, light is five hours in reaching us; it is years from the nearest fixed star, and centuries from the nearest nebulæ. Sir William Herschel stated, when writing upon the power of telescopes to penetrate space, that the light seen by him at that time by means of his powerful telescope cannot have been less than one million and nine hundred thousand years in its progress. Great, however, as is the velocity of light, it is outstripped by that of electricity. Peschel truly observes: "A cannon-ball moving with a uniform velocity of 2450 feet in a second, would be $6\frac{1}{3}$ years, and sound would be 14 years, in coming to us from the sun; a cannon-ball moving with the same velocity as we have already supposed, would be 16 hours in travelling round the circumference of our earth, a space which light traverses in one-eighth of a second: the velocity of light must therefore be half a million times that of a cannon-ball, and more than a million times that of sound. At the rate of 4 miles in $3\frac{1}{2}$ minutes, being the speed at which Brunel, in 1841, travelled on the Great Western Railway, it would require more than 137 years to go from our earth to the sun."

When light meets with an opaque body through which it cannot pass, it is stopped, and darkness produced on the opposite side. This is a shadow, and during night we are living in the shadow of the earth; the light from other bodies, however, prevents there being total blackness or darkness. Thus, if a globe be held before a gas-light or candle, the shadow on the opposite side to the light will only be faint; but if the gas-light be lowered, or a smaller candle replace the other, the shadow will be deepened, though not entirely dark, from the reflection of the wall or other objects. As in the case of the sun *a a* (fig. 134) to the earth, a large luminous body illuminating a small opaque one *c*, the shadow *e e* produced gradually tapers off to a small point *d*. But when the luminous body *a* is smaller than the opaque one *b*, the shadow *c d* will gradually increase in size, fig. 135. This may be familiarly illustrated in a room with a candle: if the candle be at some distance from a person who is between it and the wall, the shadow will be about the same size as the person's body; but as the candle is brought nearer to him the shadow will be enlarged. If two candles be placed in different directions beyond an opaque body, there then will appear two shadows; if three, three shadows; and so on.

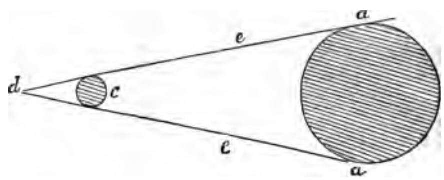


fig. 134.

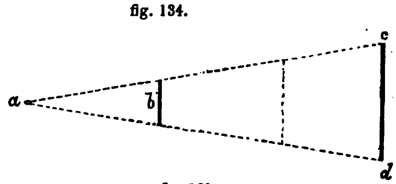


fig. 135.

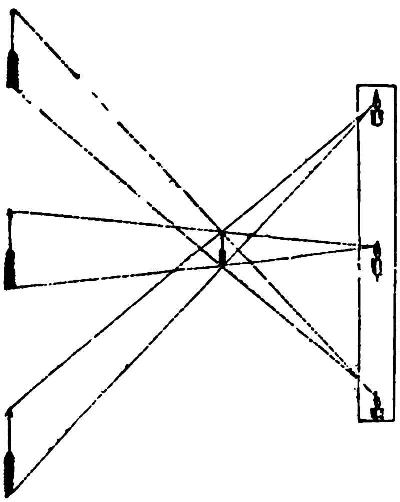


fig. 136.

There is this singular property in the rays of light, that they pass directly onward in a straight line, crossing each other in every direction, but never interfering the one with the other. Thus, as shewn in the illustration, fig. 136, the light from three candles cross, the one proceeding in a line, and the others at angles; and each reflects different faint shadows of the object placed in the centre. The small triangle just beyond the little arrow or figure will be a strong shadow, because in that part no light from any of the candles reaches there, being obstructed by the figure and enclosed by the lines indicating the shadows from the three candles.

If a hole be made through a partition, and six or more candles be placed on one side of it, the rays from each will pass through the hole and cross each other, reflecting the light of each on a part of that apartment where the candles are not. This is illustrated in fig. 137, where *a, b, c, d,* and *e* are candles placed at one side of a shutter or wall *f g*, the rays from which candles pass through the aperture, and are reflected on the wall at the points *h, i, k, l,* and *m*.

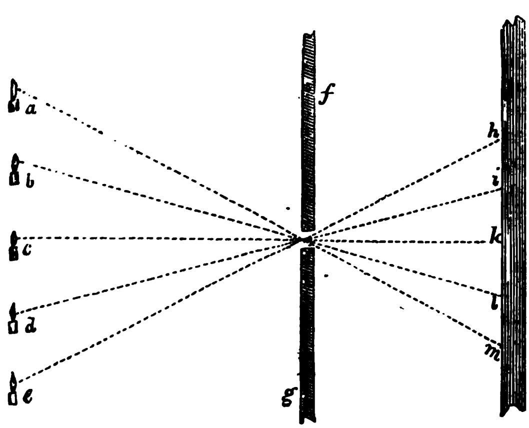


fig. 137.

The sun, when it blesses the earth with its presence in the early morn, and again when departing in the evening, causes long shadows to be thrown from opaque bodies; but when nearly vertical, at noon, the shadows are small.

An eclipse of the moon occurs by her passing through the long shadow of the earth cast beyond it.

The sense of seeing is the reception of rays on the expanded nerve of vision, the retina of the eye; and the effect produced is not merely transient, but lasts for about the eighth part of a second. The rays diminish in intensity according to distance, corresponding with the laws that

govern several other bodies, as those of motion, but independent of other laws, as those of gravity; thus light diminishes as the square of the distance increases, in the proportion of 1, 4, 16, &c. to the distances 1, 2, 3, 4, &c.: but like the atmosphere, its volume at the same time increases; for if a candle be lighted on a dark night and placed in an open prominent position, the light will fill a sphere of a mile in diameter. The number of its rays baffles all attempts at calculation, for were the entire space covered with eyes, all would receive a portion and become sensible of its presence. The various planets receive heat and light according to their distance from the sun's rays.

We have observed that opaque bodies reflect light, and transparent bodies transmit it; but when a ray of light enters a transparent mass, that is, passes from one medium into another in an oblique direction, the direction of the ray is changed both on entering and leaving: this is called *refraction*. In the valuable treatise on this subject by Dr. Arnott he remarks: "But for this fact, which to many persons might at first appear a subject of regret, as preventing the distinct vision of objects through all transparent media, light could have been of little utility to man. There could have been neither lenses as now, nor any optical instruments, as telescopes and microscopes, of which lenses form a part, nor even the eye itself." Rays of light falling perpendicularly upon a surface of glass or other transparent substances, pass through without being bent from the original line of their direction. Thus, if a ray passes from *k* perpendicularly to the surface of the piece of glass at *e*, fig. 138, it will pass to *h* in the right line *k, e, o, g, h*. But if the same ray be directed to the surface *e* obliquely, as from *a*, instead of passing through in a direct line to *b* in the direction *a, e, m, b*, it will be refracted to *d*, in a direction approaching nearer to the perpendicular line *k h*. The ray *a c* is termed the ray of incidence, or the incident ray; and the angle *a e k* which it makes with the perpendicular *k h* is called the angle of incidence. That part of the ray from *e* to *d* passing through the transparent medium is called the ray of refraction, or the refracted ray; and the angle *d e g* which it makes with the perpendicular is called the angle of refraction. The ray projected from *a* to *e* and refracted to *d*, in passing out of the transparent medium as at *d*, is as much bent from the line of the refracted ray *e d*, as that was from the line of the original ray *a e b;* the ray then passes from *d* to *c*, parallel to the line of the original line *a e b*. It follows, then, that any ray passing through a transparent medium, whose two surfaces, the one at which the ray enters and the one at which it passes out, are parallel planes, it is first refracted from its original course; but in passing out, is bent into a line parallel to and running in the same direction as the original

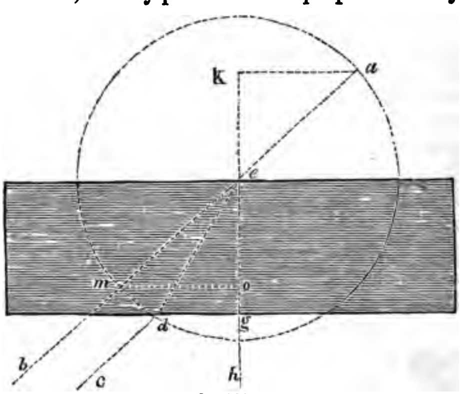


fig. 138.

line, the only difference being that its course at this stage is only shifted a little to one side of that of the original. If from the centre *e* a circle be described with any radius, as *d e*, the arc *g m* measures the *angle of incidence g e m*, and the arc *g d* the *angle of refraction g e d*. A line *m o* drawn from the point *m* perpendicular to *h k* is called the *sine* of the angle of incidence, and the line *d g* the sine of the angle of refraction. From the conclusions drawn from the principles of geometry, it has been discovered by learned men, that in any particular transparent substance the sine of the angle of incidence *m o* has always the same ratio to the sine *d g* of the angle of refraction, no matter what be the degree of obliquity with which the ray of incidence *a e* is projected to the surface of the transparent medium. If the ray of incidence passes from air obliquely into water, the sine of incidence is to that of refraction as 4 to 3; if it passes from air into glass, the proportion is as 3 to 2; and if from air into diamond, it is as 5 to 2.

"It is important to remark," says Dr. Arnott, "that for the same substance, whatever relation holds between the obliquity of a ray and the refraction in any one case, the same holds for all cases. If, for instance, where the obliquity as measured by its sine is 40, and the refraction is half or 20, then in the same substance an obliquity of 10 will occasion a refraction of 5, and an obliquity of 4 will occasion a refraction of 2, and so on. As a general rule, the refractive power of transparent substances or media is proportioned to their densities. It increases, for instance, through the list of air, water, salt, glass, &c. But Newton, while engaged in his experiments upon the subject, observed that inflammable bodies had greater refractive power than others; and he then hazarded the conjecture, almost of inspired sagacity, and which chemistry has since so remarkably verified, that diamond and water contained inflammable ingredients. We now know that diamond is merely crystallised carbon, and that water consists altogether of hydrogen, or inflammable air, and oxygen. Diamond has nearly the greatest light-bending power of any known substances, and hence comes in part its brilliancy as a jewel. No good explanation has been given of the singular fact of refraction; but to facilitate the conception and remembrance of it, we say that it happens as if it were owing to an attraction between the light and the refracting body or medium."

It ought always to be borne in mind, "that we see every thing by means of the rays of light which proceed from it."

fig. 139.

There is another axiom in optics to be remembered, which is, that "we see every thing in the direction of that line in which the rays approach the eye last." This is popularly illustrated by placing a piece of silver coin in an empty basin and retiring till the edge of the basin prevents it being seen; another person then pouring water into the basin gently,

so as not to disturb the coin, it will come again into view of the person who retired from it. If the eye be at g and the coin at c, when the basin is empty, the rays of light flowing from c must go in the direction of $c\,h\,g$, for then they cannot go in the direction of $h\,g$, the side of the basin preventing the eye from seeing the place of the coin c. But as soon as water is poured into the vessel, the coin becomes visible by the refraction of the ray; it is not seen in the situation which it really occupies, but an image of it higher up in the basin; for as objects appear to be situated in the direction of the rays which enter the eye, the coin will be seen in the direction of the refracted ray $g\,h\,e$. This also exemplifies that rays of light entering from a denser to a rarer atmosphere are bent from the direct line.

It is this deception on the vision that causes the bottom of a place in which there is clear water to appear nearer the surface than it really is. How often, when the sultry feeling of summer has been felt, the sun's rays glancing on the pellucid stream, rendering it a mirror of the ethereal sky above, has youth been induced by the tempting appearance and apparent safety as to depth, plunged in, and found himself lured to a watery grave! We may remark, however, this difference as regards the illustration we have given of the coin,

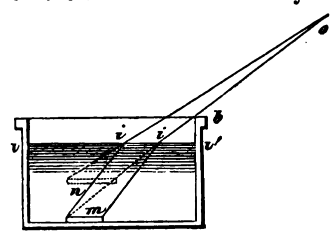


fig. 140.

that the formation of an image above the true place of the body does not depend on the situation of the eye; for when we look at the bottom of a clear river or pond perpendicularly, then it appears in its natural depth, because there is no refraction; but if we look in another direction, the rays which it reflects are refracted in their passage from the water into the air, which causes the bottom to appear nearer the surface, and consequently the water more shallow.

Thus we should not be able to perceive the object m in the vessel $v\,v'$ (fig. 140), if the latter were empty, and the eye situated at o. Upon water being poured into the vessel, the rays passing from m to $i\,i$ are refracted on emerging from the water, and the object will now appear to the eye to be at n, much higher than its real position.

Often do persons when loitering near a stream, in mere idleness thrust their walking-stick into the water, and amuse themselves in seeing the bent appearance it presents, and vainly endeavour to place it in a position to avoid such a vexatious disturbance.

The angler when he dips his rod in the stream sees it twisted, and can only judge of its position from that portion which is out of the water.

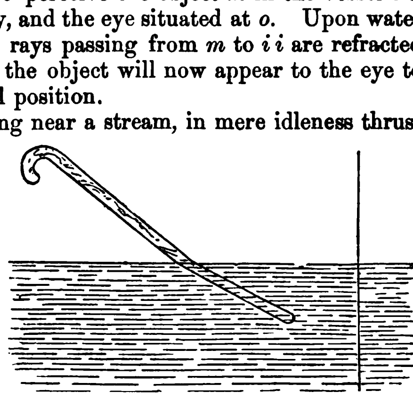


fig. 141.

The oars of a boat appear broken at the part that touches the water. The image of the position in the water seems apparently formed above the object itself.

In spearing salmon or eels the experienced fisherman allows for this deception of vision, as the sportsman calculates distance when he fires at a bird flying in the air.

Like every other provision of Providence for man, this refractive phenomenon is beneficial. When light leaves unknown space and enters our aërial atmosphere, it is refracted; and this prevents our seeing the heavenly bodies in their real position, seeming to be a little higher than they really are, excepting when directly over our heads.

Thus it is we do not see the sun and moon in the places where they really are situated. To a person on the earth at E, the sun, moon, or star that is at S appears as if at C, from the rays that proceed from S, entering the atmosphere surrounding the earth at R, being bent. The ray coming in a line from A to D seems to the eye to come from B, although in reality it comes from A, and is bent at D to the line ending at E. From this circumstance we see the image of the sun before the sun itself; thus we have addition to the length of our days both by the morning dawn and the evening twilight. Were it otherwise, we should suddenly pass from a glare of light into intense darkness, which would be injurious to the eye, and produce many evils of which, under the present wise and kind ordination, we are happily unconscious. If the sun were immediately over our heads, then the rays would proceed in a straight line without being refracted, and we should see it in its actual position, which is sometimes the case in the torrid zone. Still this must be remembered, that as we receive the rays of the sun eight and a quarter minutes after it has left its source, the sun must have shifted its position ere it is observed, therefore we see it at the place where it was when the rays left to proceed on their journey. In these remarks we have been supposing the sun to be vertical over our heads, and also spoken of its apparent motion, produced by the diurnal rotation of the earth; but the effect would have been the same whether the sun or the earth moved, and hence we have referred to the subject as things seem to be.

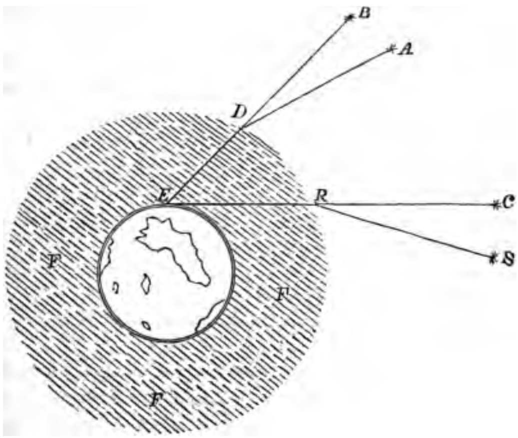


fig. 142.

A knowledge of the laws of refraction explained that which had often been a subject of wonder and fear to the ignorant, generally known by the term mirage, which is a reflection or refraction of distant lands, cities, and vessels in the heavens. In some countries these appearances are of frequent occurrence, arising from the atmosphere between the eye and the object being more rarefied or dense in one part than in another. Captain Scoresby relates seeing his father's ship inverted in the air when below the

horizon. The captain says, "It was so well defined, that I could distinguish by a telescope every sail, the general rig of the ship, and its particular character, insomuch that I confidently pronounced it to be my father's ship, the *Fame*, which it afterwards proved to be; though, on comparing notes with my father, I found that our relative position at the time gave our distance from one another very nearly thirty miles, being about seventeen miles beyond the horizon, and some leagues beyond the limit of direct vision. I was so struck with the peculiarity of the circumstance, that I mentioned it to the officer of the watch, stating my full conviction that the *Fame* was then cruising in the neighbouring inlet."

There are numerous well-attested facts of distant objects being seen close at hand, and of gigantic figures in fogs and mists, arising from a reflection in the atmosphere. The following account of the singular phenomenon called the Spectre of the Brocken, in the Hartz mountains in Germany, is given by Mr. Hane:

"The sun arose about four o'clock, and the atmosphere being quite serene, towards the east his rays could pass without any obstruction over the Heinrichshöhe. In the south-west, however, towards Achtermannshöhe, a brisk west wind carried before it thin transparent vapours, which were not yet condensed into thick heavy clouds.

About a quarter past four I went towards the inn, and looked round to see whether the atmosphere would permit me to have a free prospect to the south-west; when I observed at a very great distance, towards Achtermannshöhe, a human figure of a monstrous size. A violent gust of wind having almost carried away my hat, I clapped my hand to it by moving my arm towards my head, and the colossal figure did the same.

The pleasure which I felt on this discovery can hardly be described; for I had already walked many a weary step in the hopes of seeing this shadowy image, without being able to gratify my curiosity. I immediately made another movement by bending my body, and the colossal figure before me repeated it. I was desirous of doing the same thing once more, but my colossus had vanished. I remained in the same position, waiting to see whether it would return, and in a few minutes it again made its appearance on the Achtermannshöhe. I paid my respects to it a second time, and it did the same to me. I then called the landlord of the Brocken; and having both taken the same position which I had taken alone, we looked towards the Achtermannshöhe, but we saw nothing. We had not, however, stood long when two such colossal figures were formed over the above eminence, which repeated our compliments by bending their bodies as we did, after which they vanished. We retained our position, kept our eyes fixed on the same spot, and in a little time the two figures again stood before us, and were joined by a third. Every movement we made by bending our bodies, these figures imitated, but with this difference, that the phenomenon was sometimes weak and faint, sometimes strong and well-defined. Having thus had an opportunity of discovering the whole secret of this phenomenon, I can give the following information to such of my readers as may be desirous of seeing it themselves.

When the rising sun—and according to analogy the case will be the same as the setting sun—throws his rays over the Brocken upon the body of a man standing opposite to fine light clouds floating around or hovering past him, he needs only fix his eyes steadfastly upon them, and in all probability he will see the singular spectacle of his own shadow, extending

to the length of five or six hundred feet, at the distance of about two miles before him."

We now come to the account of those useful portions of optical instruments, the proper construction of which gives them value, and are called lenses. They consist of glass ground to a particular form, best suited to collect and disperse rays of light.

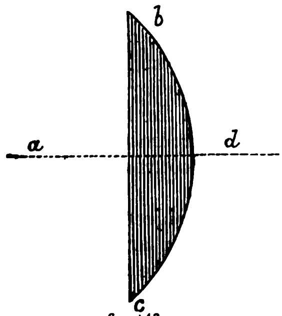


fig. 143.

A plano-convex lens, fig. 143, has one side flat and the other, *b c*, convex. The axis of a lens is a line passing through its centre, as *a d*. When rays approach each other to meet at one spot, they are said to converge; thus the parallel rays B B B B passing through the plano-convex lens D, fig. 144, converge until they meet at C; if the light were reversed, and C was a candle, then the rays would, as it were, retreat from each other in approaching the lens, and then they are said to diverge. C is termed the focus of the lens D, for the parallel lines passing through it all meet there. Now the distance of the focus from the centre or middle of the glass may be known by drawing a circle around it, as it is equal to the diameter of the sphere of which the convex surface forms a part. It will be remembered that rays of light passing out of a rarer to a denser medium incline to the axis or perpendicular, so that the rays B B B B passing out of the lens bend to the axis or perpendicular ray A C. C is also called the principal focus, or the focus of parallel rays, and the distance from the middle of the glass the focal distance.

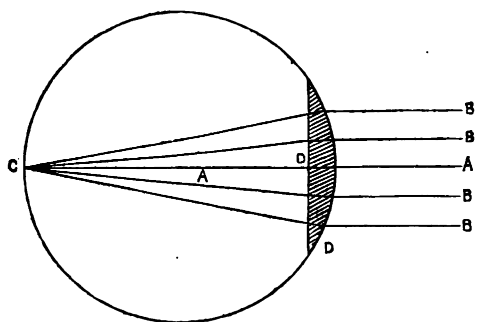


fig. 144.

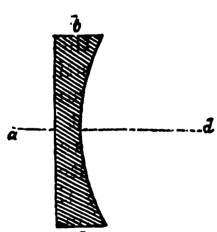


fig. 145.

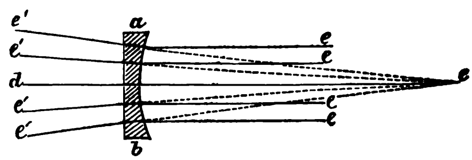


fig. 146

A plano-concave lens, *b c*, fig. 145, is flat at one side and concave at the other; and the parallel rays diverge after passing through it, as if they had come from a radiant point at the distance of the diameter of the concavity of the lens: this is called the imaginary focus. Thus the rays *e e*,

fig. 146, are refracted to $e'e'$, as if they had proceeded from the point *e*.

A double-concave lens, fig. 147, is concave at both sides. When parallel rays of light fall upon it, instead of converging to the parallel ray, they seem drawn to the lens, and diverge from the parallel ray both in their passage through the lens and afterwards upon leaving it. The imaginary focus is at the distance of the radius of convexity.

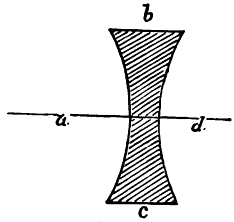


fig. 147.

A meniscus lens, fig. 148, or moon-shaped, is convex at one side $b\,c'$, and concave at the other $e'e$; its effect is according to the manner in which it is applied. But with regard to this, as well as other lenses formed of glass, the angle of incidence always bears the same ratio to the angle of refraction, whether it be with regard to plane or spherical surfaces, concave or convex, or in whatever direction the rays may be refracted.

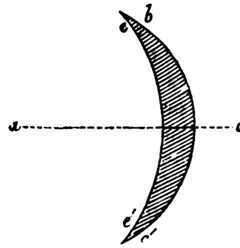


fig. 148.

A double-convex lens is convex on both sides. In the double-convex lens the focus is equal to the radius of the spherical surface. Rays of light falling parallel to the axis are refracted, so that on quitting the surface of the lens they converge until they cut the axis. If the rays fall near the

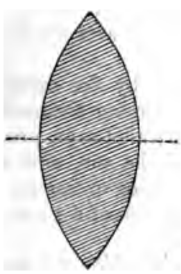


fig. 149.

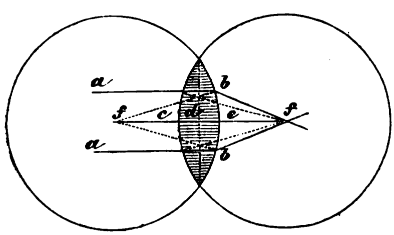


fig. 150.

axis as *a b*, they will meet after refraction in the point *f*, which is the *focus*. Its distance *f c* from the focus is termed the *focal distance*, as is *f d*; the latter is also called the optical centre. The focus of parallel rays is known as the *principal focus*, and its distance as the *principal focal distance*.

The following excellent illustration is given by Dr. Arnott in his work on Physics : " Rays falling from *a* on a comparatively flat or weak lens at L, might meet only at *d*, or even farther off ; while, with a stronger or more convex lens, they might meet at *c* or at *b* (fig. 151). A lens weaker still might only destroy the divergence of the rays, without being able to give them any convergence, or to bend them enough to bring them to a point at all, and then they would proceed all parallel to each other, as seen at *e* and *f*; and if the lens were yet weaker, it might only destroy a part of the divergence, causing the rays from *a* to go to *g* and *h* after passing through, instead of to *i* and *k* in their original direction.

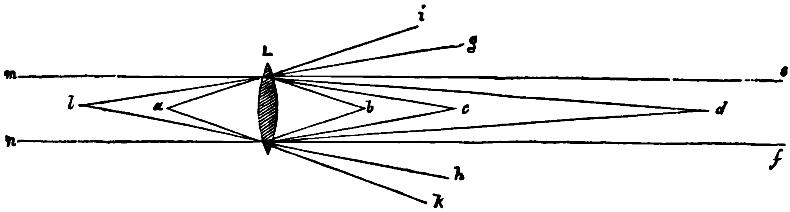


fig. 151.

In an analogous manner, light coming to the lens in the contrary direction from *b*, *c*, *d*, &c., might, according to the strength of the lens, be all made to come to a focus at *a* or at *l*, or in some more distant point; or the rays might become parallel, as *m* and *n*, and therefore never come to a focus, or they might remain divergent.

It may be observed in the above figure, that the farther an object is from the lens, the less divergent are the rays darting from it towards the lens, or the more nearly do they approach to being parallel. If the distance of the radiant point be very great, they really are so nearly parallel that a very nice test is required to detect the non-accordance. Rays, for instance, coming to the earth from the sun, do not diverge the millionth of an inch in a thousand miles. Hence, when we wish to make experiments with parallel rays, we take those of the sun.

Any two points so situated on the opposite sides of a lens, as that when either becomes the radiant point of light, the other is the focus of such light, are called *conjugate foci*. An object and its image formed by a lens must always be in *conjugate foci*; and when the one is nearer the lens, the other will be in a certain proportion more distant.

What is called the principal focus of a lens, and by the distance of which from the glass we compare or classify lenses among themselves, is the point at which the sun's rays, that is, parallel rays, are made to meet; and thus, by holding the glass in the sun, and noting at what distance behind it a little luminous spot or image of the sun is formed, we can at once ascertain the focus of a glass, as at *a* for the rays *e* and *f*."

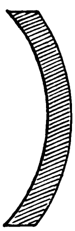


fig. 152.

A concavo-convex lens, fig. 152, is one in which the two surfaces agree in general form with the meniscus lens, but differ in this respect, that the concave surface is a part of a smaller sphere than that of the convex side; the two surfaces, if produced, would never meet as they do in the meniscus.

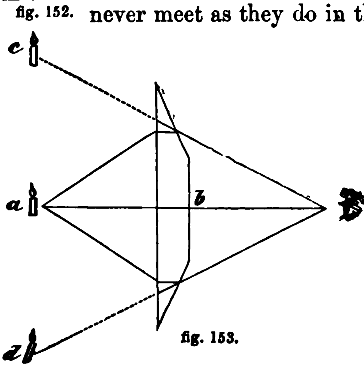


fig. 153.

A multiplying-glass is a convex lens having a number of faces cut at angles to each other upon it, and objects seen through it are multiplied. Thus the rays from a candle or other object from *a* to *b* are refracted in passing through the glass, so that the eye where they meet sees three objects, one direct at *a*, and two by refraction at *c*, *d*.

We may here state that what is understood by a pencil of rays, is

when rays *aa* diverge or spread out from a single point of a luminous body *b*. A ray is always intended to signify a single line of light proceeding from a luminous object.

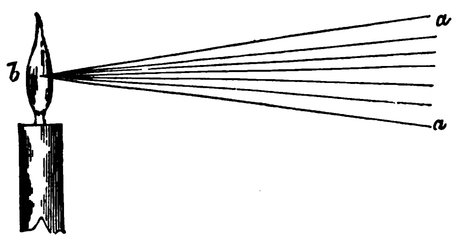


fig. 154.

Either a double-convex or plano-convex lens, it is seen, will refract the rays of the sun falling on its surface to a point on the opposite side; and such constitutes a burning lens, and the point to which they arrive is hence called the focus. The larger the surface, the more powerful will be the focus: suppose a lens four inches diameter have a focus at one foot distance, giving an image of the sun the one-tenth of an inch in diameter, 1600 times less than the surface, consequently the rays at the focus will be this much denser than at the surface. The most remarkable burning lens was that made by Mr. Parker for Dr. Priestley, and now in the possession of the Emperor of China. Fig. 155 represents it as mounted on a stand. It was formed of flint glass nearly three feet in diameter, having when fixed a clear surface of two feet eight inches and a half; its weight was 212 pounds, its focal length six feet eight inches, and the diameter of the image of the focus one inch; but by applying another lens, the focus was reduced to half an inch in diameter. It produced a heat that set fire instantly to hard, green, or wet wood; it melted iron plates in a moment; and tiles, slates, and earths became vitrified. Sulphur, pitch, and all resinous bodies melted under water; fir-wood exposed to the focus under water did not seem changed, but when broken, the inside was burnt to coal. If a cavity was made in a piece of charcoal, and the substances to be acted on were put in it, the effect of the lens was much increased: any metal thus enclosed in the cavity of a piece of charcoal melted instantly, the fire sparkling like that of a forge; the ashes of wood, paper, linen, and all vegetable substances were turned into a transparent glass. The substances most difficult to be wrought on were those of a white colour. All metals vitrified on a china plate, when it was so thick as not to melt, and the heat was gradually communicated. When copper was thus melted, and thrown quickly into cold water, it produced so violent a shock, as broke the strongest earthen vessels, and the copper was entirely dissipated. It fused twenty grains of gold in four seconds; of silver in three seconds; ten grains of platina in three seconds, and as much flint in thirty seconds; yet there was no

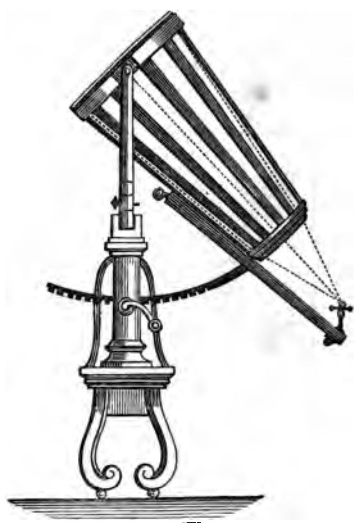


fig. 155.

heat at a small distance from the focus. The finger could be placed in the cone of rays, within an inch of the focus, without any hurt; when Mr. Parker placed his finger at the focus, he said it did not feel like ordinary burning, but the sensation was that of a sharp cut with a lancet. The water when clear, and in a clean glass decanter, was not even warmed; but with iron in it, or ink, it was made to boil.

Anamorphoses are produced from cylindrical concave mirrors; and as they are placed upright or on their sides, the image of the picture is distorted into very long or broad images. Thus a person viewing his physiognomy in one is astonished to find his face has become very long, when no particular grief affects him; or he is made aware of being excellently suited for a study of a print to represent "laugh and grow fat," by seeing his mouth extended from ear to ear. They are sold by opticians for the amusement of those who wish to see their friends misrepresented. Some persons have employed themselves by painting distorted pictures, which they shew by means of these glasses to possess every beauty and correctness.

If a room be darkened by closing in the window-shutters, and a small hole be bored to admit a ray of light, and it fall upon a mirror, a sheet of paper, or white article, it will cause a light in the apartment, but if upon a black article it will be absorbed.

If a convex lens be placed in the hole of the shutter *g*, it will concentrate the rays of light, and represent on the opposite wall a picture of the different objects from which the rays proceed, but in an inverted position.

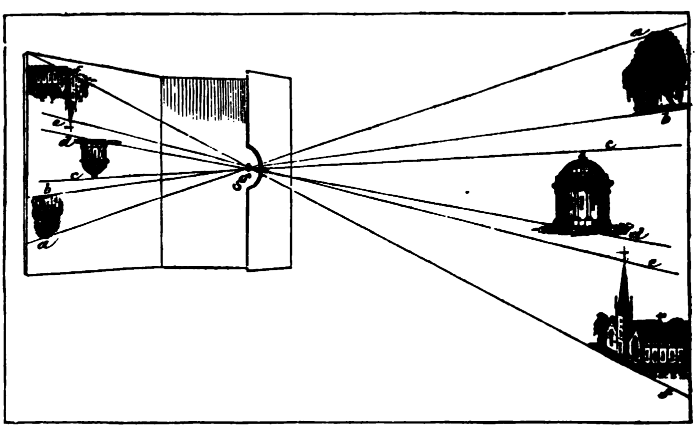


fig. 156.

The rays from the top of the tree *a* proceed onward and are represented at *a;* the rays of light moving in a straight line and entering the room in a descending direction, by their thus continuing, fall on the lower part of the wall opposite the hole in the shutter, whereby the top of the tree is seen inverted instead of upright as in the view. The rays from the bottom of the tree *b* on entering the hole in the shutter ascend, and thus this part of the tree *b* appears highest. The rays from the church *c d* represent its figure on the wall in the manner *c d*. It will thus be seen

that the rays from different directions proceed independently in a straight line, reversing the position from the highest to the lowest; or the rays from the right to the left, from the lowest to the highest; or the rays from the left to the right, excepting the mausoleum in the centre E F, which although upside down, its situation in the picture is the same: this is from its being exactly in front of the hole in the shutter; and as its rays fall perpendicularly, so do they proceed to the wall. In fact, the whole is an inverted miniature representation of the landscape; and is exactly the same principle on which the pupil of the eye portrays objects on the retina, and that on which the camera obscura acts, as will be afterwards shewn.

A triangular prism of glass possesses the property of bending the rays of light as previously shewn. Thus the ray R E entering the prism P at the point E is refracted in the direction of the line E F, and on leaving the prism at F is again refracted in the direction F G; but all the rays constituting white light are refracted in a different degree, as will be afterwards explained.

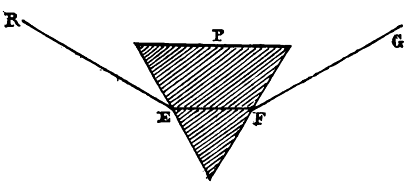


fig. 157.

Refraction through Prisms.—A prism is a solid body included between three or more faces, each of these being a parallelogram; but the prism here represented is a triangular one of crown glass.

In the diagram, fig. 158, the faces of the glass prism are A B and D E, and if of crown glass will have a refractive power of 1.525. Now if a ray of light, F G, fall on the face of the prism at G, draw a line, H I, perpendicular to the face A B, then with a pair of compasses from a scale of equal parts take the refractive power 1.525; then place one point of the compasses on G F, move it along to some point F, till the other point falls on a point J of G H, so that F J is perpendicular to G H; then with G as a centre, with the distance G F describe the circle I F H. On the scale before-named with the compasses take 1.000 and set it off from G towards A; this will give the point W; through this point draw W K parallel to H I; then from the point K, where this line cuts the circle, draw K L perpendicular to H I. Thus, then, F J is the sine of the angle of incidence, and L K the sine of the angle of refraction, and the line G K M drawn through K represents the refracted ray.

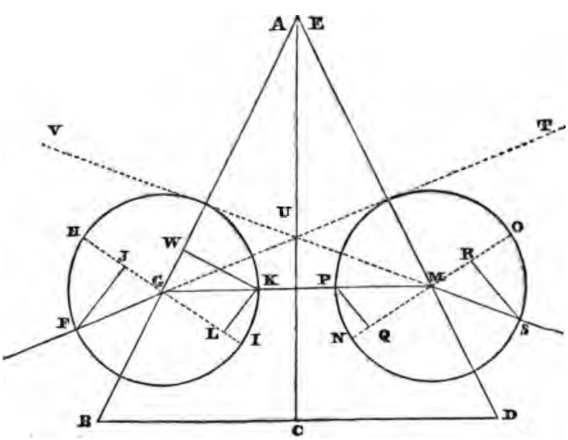


fig. 158.

Then as the ray G M meets the second refracting surface at M, through it draw N O perpendicular to E D, and with M as a centre, and distance G F, describe a circle and construct the figure P N S O, exactly similar to the one above described.

The ray departing from the lens into the air in this last instance, P Q is the sine of the angle of incidence, and R S the sine of the angle of refraction, therefore the line M S drawn through M will be the refracted ray. It will be seen that the prism, from its powers of refraction, has bent the ray, which if not refracted would have proceeded direct onward to T, and gives the angle T U S as the amount of the deviation from a direct line. Now if a ray of light fall on the face of the prism at F G, by looking at S, it will be seen at V proceeding along the line M U V, and the angle V U F will be equal to the angle T U S.

On the refracted ray G M traversing the prism, it proceeds in a direct line parallel to B D; and on this occurring the angle of deviation F U V is not so great as if the ray fell in any other position, or the prism were differently constructed. If a candle be used to give the ray, then by looking at M of the prism and turning it round, the image of the candle will be stationary at V, which shews the line G M is parallel to B D; but in any other position the image will move towards V.

If a line be drawn from A E to C, so as to divide the base of the prism into two equal parts, when in the position as represented in the diagram, then the angle of refraction K G L on the surface of the prism where the ray enters is equal to B A C, half of the angle of the prism. Then as half this angle has been ascertained, and as it is easy by a dividing instrument to measure the angle of incidence, F G H is at once known, as well as the angle of refraction O M S on the other surface of the prism; and having ascertained them on one side, they are easily known on the other. Then dividing the sine of the angle of incidence by the sine of the angle of refraction, the refractive power is gained.

If a prism be placed opposite a hole of a shutter admitting a ray of light to a darkened room, a singular effect takes place, for a knowledge of which we are indebted to Sir Isaac Newton; this was no less than that the pure ray of white light is composed of several brilliant colours. Before this great discovery light was considered to be a simple homogeneous body. Thus if the ray be transmitted through the prism, and thrown on a screen opposite, seven distinct colours will appear in the following order:

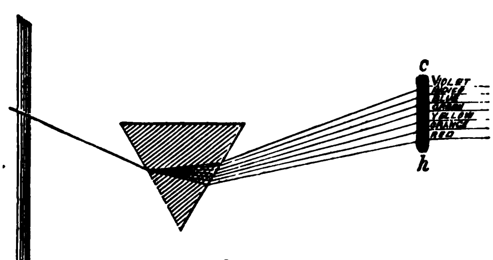


fig. 159.

This dissection of a ray of light, then, shews it to be composed of red, orange, yellow, green, blue, indigo, and violet colours. The red

rays, it will be observed, are the least turned out of their course, and the violet the most so; and the others possess this property more or less as expressed on the screen where they are represented: the breadth of the oblong image of the colours is equal to the diameter of the hole in the shutter. It is a curious coincidence, that the number of colours agrees exactly with the different divisions of the number of notes in music. Supposing the division on the prismatic spectrum, as the image of the ray on the screen is called, be divided into 360 parts, the proportion of the red will be 45 parts, the orange 27, the yellow 48, the green and blue 60 each, the indigo 40, and the violet 80. Now if a circular piece of card be divided into these proportions and coloured accordingly, then whirled rapidly round, the colours would be so blended as to appear of a dirty white; were the colours as pure as those painted by nature, there can be no doubt but the appearance would be a perfect white. But the most convincing proof that those colours constitute a pure white ray is by reuniting them. Thus if the coloured rays are allowed to fall upon a double convex lens, fig. 160 L, they pass through it and converge to a focus, when they appear as a white ray the same as before passing through the prism. The ray R entering the hole in the shutter falls upon the prism P, and is separated into the seven colours C, which passing through the lens L, unite in a white ray at the focus F. Thus is the ray separated and again joined into its former body.

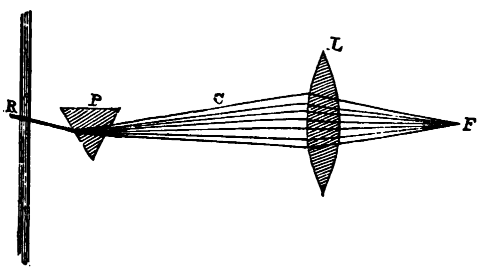


fig. 160.

The solar or prismatic spectrum is only at particular parts vivid as to each distinctive colour, for they mingle and blend the one into another in such a manner as to render it impossible to say where each begins or ends. The seven colours were named primary, it being believed that they were simple or homogeneous, especially as when reflected through another prism they retained their individuality. Artists, nevertheless, proved that red, blue, and yellow would form all the beautiful tints of the prismatic spectrum; therefore that the other colours were heterogeneous, or compounds. Still, as the colours reflected could not be analysed into others than they appeared, a difficulty existed that prevented the fact being established of their not being primary colours. Buffon shewed, by placing a red, yellow, or blue spot on a white or black ground, and looking steadfastly at it, the eye perceives in each case a border fringing the coloured spot, the tints of which are composed of the three colours: for instance, a red spot will shew a green border—and green is composed of blue and yellow; a yellow spot will appear to have a violet border, which colour is made by mixing blue and red; and a blue spot will have an orange border, which is yellow and red. Many have been the experiments made by scientific persons to satisfactorily solve this question; and Sir David Brewster and others have concurred in the opinions of Mr. Hay of Edinburgh, as expressed in his work on the *Laws of Harmonious Colouring*. Mr. Hay states that he could

not by analysis prove that there were only three colours, but that he succeeded in proving it to his own satisfaction, synthetically, in the following manner:—

"After having tried every colour in succession, and finding that none of them could be separated into two, I next made a hole in the first screen in the centre of the blue of the spectrum, and another in that of the red; I had thereby a spot of each of these colours upon a second screen. I then, by means of another prism, directed the blue spot to the same part of the second screen on which the red appeared, where they united and produced a violet as pure and intense as that of the spectrum. I did the same with the blue and yellow, and produced the prismatic green; as also with the red and yellow, and orange was the result. I tried, in the same manner, to mix a simple with what I thought a compound colour, but they did not unite; for no sooner was the red spot thrown upon the green than it disappeared.

"I tried the same experiment with two spectra, the one behind, and of course a little above the other, and passed a spot of each colour successively over the spectrum which was farthest from the window, and the same result occurred. It therefore appeared to me that these three colours had an affinity to one another that did not exist in the others, and that they could not be the same in every respect except colour and refrangibility, as had hitherto been taught.

* * * * *

"The three homogeneous colours, yellow, red, and blue, have been proved by Field, in the most satisfactory manner, to be in numerical proportional power as follows:—yellow, three; red, five; and blue, eight. When these three colours are reflected from any opaque body in these proportions, white is produced. They are then in an active state, but each is neutralised by the relative effect that the others have upon it. When they are absorbed they are in a passive state, and black is the result. When transmitted through any transparent body, the effect is the same; but in the first case they are material or inherent, and in the second impalpable or transient. Colour, therefore, depends entirely on the reflective or refractive power of bodies, as the transmission or reflection of sound does upon their vibratory powers."

It is now a generally received opinion, that different bodies, according to the manner in which their minute particles are arranged, have the power of absorbing and reflecting rays; and consequent on the proportions of the rays absorbed and reflected does the colour depend, and that it is not a part of the object itself. Herbage appears to absorb all the portions of the rays except green; this it reflects, therefore herbage seems to the eye of a green colour. A heartsease differs in texture when its flowers vary in colour. A poppy appears scarlet, as it absorbs all the colours of the rays except red, and hence its peculiar tint; but if it be held under green glass it will appear black, as the poppy only reflects the red ray which the green glass absorbs. The red of the lovely fragrant rose, the blue of the humble modest violet, the yellow of the gay and brilliant jonquil, are owing to their absorbing all the rays excepting the red, blue, and yellow. A white colour is the reflection of all the rays; a black their entire absorption. The palely tinted rose, almost white, shews that it reflects nearly all the coloured rays. Without light, the face of beautiful

variegated nature would be a world in mourning; light comes and enlivens the scene, painting the exterior with a beauty, richness, delicacy, and harmony, that man vainly attempts to rival.

Plants close their flowers at sunset, and open them at sunrise.

The reason of flowers and leaves of plants turning to the light is that the part of the stem opposite to its influence becomes more hardened than the other parts; the stronger part, therefore, hardened and condensed by the light, contracts on becoming so, and the softer part behind, yielding to this contraction, gives way and appears to stretch over to participate in the strengthening influence of light. From this action of the light, the vital fluid circulates more actively, consequently more wood is formed on the side next the light than on the dark side. The pith or centre line of the layers of the tree is always found out of the centre; and hence, by cutting a section of wood, it may be easily known which part has been facing the sun, and this will be found to be the hardest.

Colour is so dependent on light, that when artificially produced, as by candle or gas, from not being so pure as the rays of the sun, many things appear of a different colour, as is well known by the lady who chooses a ribbon, or the artist who attempts to paint a picture, by artificial light; a blue being mistaken for a green, and a green for a blue. Thus sometimes an artist has been surprised to find he has made the sky green and the grass blue.

On a moonlight evening we cannot distinguish the colour of a chimney-pot; and were we to take a number of pieces of different-coloured papers, examine them by the bright light of the moon, and write on the back of each the colour it appears, we should be astonished in daylight to see how much we had been deceived as to the true tint of each.

The russet tint of autumn shews that a change has taken place in the matter of the leaves, and that the green rays are no longer reflected, but a sickly mixture of colour, indicative of the decline of the principle of life, and a fitting prelude to the nipping colds of winter. This autumnal tint which succeeds the healthful and refreshing green arises from the sap becoming languid, when an acid is generated, which acting on the particles of the leaves that reflected blue and green rays, a yellow and red tint is the result.

If vermilion, powder-blue, and light chrome-yellow be intimately mixed, without rubbing, then the powder be allowed to fall in a stream in the sunshine, it will appear white.

Paint the top of a humming or peg-top with red, blue, and yellow, and when made to spin with velocity the colours will be lost to the sight, and a white be seen, if the colours be proportionately painted in the manner heretofore described.

In a fog the sun appears red, from the red rays having greater momentum to penetrate the dense state of the atmosphere. The glorious tints on the rising and setting of the sun proceed from the larger amount of mists and vapours in the atmosphere, through which the oblique rays have to travel; and the red rays having the most momentum, they reach the eye more readily than the others. We can only see the rays of the sun when we look at that luminary, and then they appear white, yet the transparent atmosphere through which they pass is of a blue colour; this would seem

to be caused by the sun's rays being reflected back into the atmosphere, where, their momentum being lessened, and the blue ray having the least, that ray is principally reflected; or it may be a property of air to reflect blue, as other substances reflect particular colours. How delightfully soothing is this tint to the eye, instead of a chilling blackness, a lurid red, or a blinding whiteness!

There have been persons of defective vision who could not distinguish particular colours. Dr. Darwin, the poet and botanist, could only by shape discover the difference between a cherry and the leaves among which it grew. Dr. Dalton, the celebrated chemist, was similarly afflicted. There was also a family at York who had this peculiar defect of colour-blindness hereditarily.

Sometimes a body will transmit one kind of colour but reflect another; thus there is glass that transmits orange but reflects green. Again, it may be observed that some colours will only be observable if the material be of a certain thickness, beyond which all colour is lost, and blackness only to be seen. Leaf-gold transmits yellow, but reflects a greenish blue.

If a delicate thermometer be placed in different parts of a prismatic spectrum, the violet rays indicate the least heat, but the mercury gradually rises as we descend downwards, the red having the most; passing below the red ray, it was found a greater degree of heat existed, and that in that part there is a ray which is invisible; this has been named the calorific or heating ray. Led from this circumstance to experiments above the violet ray, another invisible ray was discovered to exist, with less heat, but possessing the property of changing the chloride of silver from white to black, and gum guaiacum from yellow to green; this is termed the chemical or actinic ray, the rays between these invisible ones being denominated the colouring or colorific rays. Now if a body giving out these invisible rays that are less bent than the red ones of the spectrum, be much heated, its rays may be as much bent as the red ones, and may then be seen, the radiating body being red-hot. More heat applied causes yellow rays to be seen, and ultimately the whole of the colours as white heat; thus some writers have come to the conclusion that heat is invisible light, and light visible heat.

Sir Isaac Newton found that different colours required different dis-

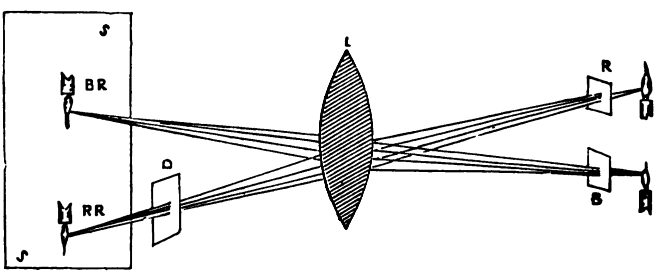


fig. 161.

tances to bring them to a focus; for instance, he placed two candles at about twice the focal length from a double-convex lens L, fig. 161, interrupting the light by a piece of red and blue glass R B, when it was found that the

images BR, RR on the screen S partook of the colours of the glass employed. By placing another screen D nearer to the lens, then the red figure was perfect on D; thus the focus for different colours was found to be at different distances from the lens, and the images were more distinct with coloured glasses than without. This is corroborated by being able to read a blue or red bill through a telescope easier than a white bill, and the having to lengthen the telescope more to read a red bill than a blue one.

From many experiments as to the power of distinguishing objects at a distance, white objects on a black ground are more readily perceived than black objects on a white ground. This subject during the rumours of war has engaged attention as to the best colour for the clothes of soldiery, and it has been decided that the least visible is a light grey. Colonel Derinzy states, that on the day before the battle of Vittoria, a Portuguese rifle company dressed in earthy brown, and a company of British Fusiliers dressed in red, were equally exposed in an undertaking to dislodge the French from a bridge, and that after the skirmish the relative losses were as two of the British to one of the Portuguese. The danger then arising from colours is 1st, red; 2d, green; 3d, brown; 4th, light grey.

The undulatory hypothesis, says Professor Daniells, accounts for the differently-coloured rays of the solar spectrum, by a difference in the frequency of recurrence of the vibrations. The other is supposed capable of vibrating in waves of different lengths; the shortest waves produce violet light, the longest red. The impression of the different colours arises precisely as that of the different sounds in air; the shortest wave in sound gives the highest note.

The periodical movements of the medium in white light regularly recur at equal intervals, five hundred millions of millions of times in a second of time—$1{,}000{,}000{,}000{,}000 \times 500$; in the sensation of redness our eyes are affected four hundred and eighty-two millions of millions of times—$1{,}000{,}000{,}000{,}000 \times 482$; of yellowness, five hundred and forty-two millions of millions—$1{,}000{,}000{,}000{,}000 \times 542$; of violet, seven hundred and seven millions of millions—$1{,}000{,}000{,}000{,}000 \times 707$.

Sir John Herschel gives the following as the length and rapidity of the coloured rays of the spectrum:—

Coloured rays.	Length of luminous rays in parts of an inch.	Number of undulations in an inch.	Number of undulations in a second.
Red	·0000256	39180	477 millions of millions.
Orange . . .	·0000240	41610	506 "
Yellow . . .	·0000227	44000	535 "
Green	·0000211	47460	577 "
Blue	·0000196	51110	622 "
Indigo	·0000185	54070	658 "
Violet	·0000174	57490	699 "

Taking, therefore, the ratio of the extreme vibrations, we may say, the sensibility of the eye has its limits within a minor sixth; while that of the ear reaches an octave.

How little do we think as we gaze on the faultless form and beauty exhibited in the flowers composing a bouquet, and inhale the delightful and invisible fragrance that fills the surrounding air, that in order to distinguish the yellow tint of the graceful laburnum, five hundred and forty-two

millions of millions of vibrations must occur; that the pendent ruby fuchsia requires the eyes to receive four hundred and eighty-two millions of millions of undulations in a second; that the lovely violet's softening tint is only distinguishable when seven hundred and seven millions of millions of vibrations have penetrated the eye!

What marvellous mechanism, then, must pervade nature, to see in the flashing of the eye the innumerable and varying hues with which the earth is carpeted, the birds gorgeously plumed, and that distinguishes the races of animals and man!

The dark lines or bands on the spectrum are supposed to be owing to the action of the solar atmosphere having the property of absorbing particular portions of the rays of light. These lines, which are called Fraunhofer's, after their discoverer, are somewhere about 600 in number. They do not follow each other with any degree of regularity, but the same position is always retained in the same kind of light: but they differ in size, number, and arrangement, in light obtained from different sources; hence it would appear that every luminous body has a system of light peculiar to itself. These dark lines in the spectrum were used by Fraunhofer for accurately measuring the refraction, the breadths of the individual colours, and the intensity of the light of luminous bodies. According to Fraunhofer's measurement, the relative intensities of the light of the different portions of the spectrum expressed numerically the luminous intensity of the extreme red ray to be 32; of the middle ray of that colour, 94; of orange, 640; between yellow and orange, 1000; green, 480; blue, 170; dark blue (indigo), 31; violet, from 5 to 6.

Professor Hunt, who has devoted much time to the investigation of the influence of the solar rays, says: "We have been hitherto led to regard the sun's rays as consisting essentially of light and heat; and these, indeed, were commonly considered as modifications of one power. Melloni has, however, shewn that plates of obsidian and black mica, which do not admit of the permeation of light, are freely penetrated by heat; and, on the contrary, that a glass stained green by oxide of copper, which offers scarcely any obstruction to light, will scarcely allow of the passage of any heat-rays. In this way it is distinctly shewn that the physical conditions of these forces are essentially different; and, in a similar manner, we may entirely obstruct the chemical agency by the use of a yellow glass, while a blue medium, which obstructs nearly all the light, admits of the free passage of the chemical radiations."

"In this manner we are made acquainted with the existence of certainly three physical agents in the solar beams—light, heat, and actinism, as the chemical power is called. Their existence may be shewn in the following manner:—If we pass a sunbeam through a glass prism, we get a coloured luminous image, *a*, fig. 162, consisting of seven chromatic bands. If we throw the same image upon black paper washed with ether, an image rapidly dries in the forms shewn in *b*, which represents the heat's rays, and proves the existence of calorific rays, which are entirely without light; and if we throw the same image on paper covered with the chloride of silver, it is blackened in the manner shewn at *c*, in which the most decided chemical change is observed to take place beyond the violet ray, where there is no light; and that in the yellow ray, where the light is at its greatest intensity, no chemical change is produced. The curved lines *d*

shew the relative points of maximum influence in the solar spectrum for each power.

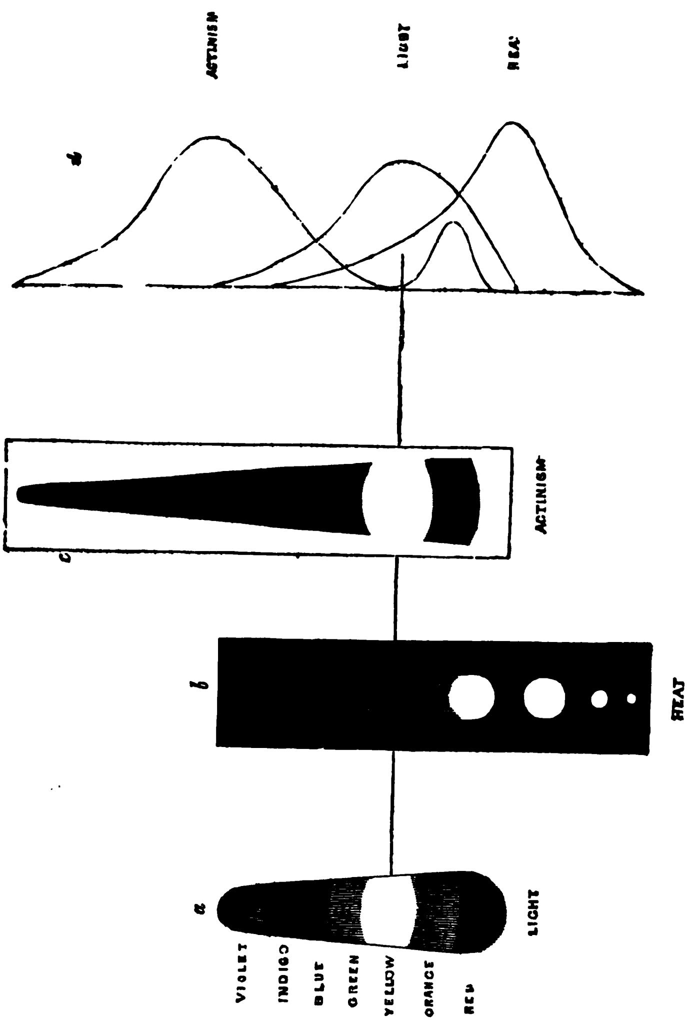


fig. 162.

" From all the phenomena which these solar powers exhibit, it is evident that they exist in a state of antagonism, and one is sometimes in a state of superior activity compared with another. Seeds require an excess of actinism to germinate; and they will not germinate in light from which the actinic power is separated. After the leaves are formed, a larger amount of light than of actinism is necessary to produce that excitation of the cellular system of the plant by which carbon is separated from carbonic acid, and wood produced. Again, the full development of the reproductive system of the plant, its flowering and fruiting, depends upon

an influence which is more closely connected with the thermic power of the sun's rays, than on either light or actinism. A very curious series of experiments has been made to prove that seeds will not germinate in pure light. Plants will not form wood in unmixed actinic radiations, nor will they flower in either light or actinism separated from the heat-rays. It has also been found that the relative proportions of light, heat, and actinism vary in the seasons of spring, summer, and autumn, which is in exact accordance with the results obtained by experiment."

"Thus so beautifully has nature disposed of the constitution of the solar beams, that these antagonistic powers are balanced one against the other in exact accordance with the requirements of organic nature. It has been discovered that the proportions of these principles are different in various parts of the globe; light and heat being at a maximum at the equator, and diminishing towards the poles; whereas actinism is at its minimum at the equator, and arrives at its maximum in the temperate zones. This fact explains the cause obviously of the gigantic vegetation of the tropics, and the gradual dwarfing of plants as we proceed towards the pole."

"Indeed, it may be proved by simple experiments that the sun's rays cannot fall upon any body, whether it be of metal, of wood, of stone, or of glass, without producing a disturbance, either molecular or chemical, on its surface; also that all bodies in nature have the power of restoring themselves during the hours of darkness to the state they were in previous to the solar disturbance. May we not hence infer, that darkness is as necessary to the inorganic body, as night and sleep to living and breathing beings? These researches, which have arisen from the discovery of photography, have already led to the elucidation of many mysteries connected with the great phenomena of nature; and the discovery of the new element *actinism* promises to lead us rapidly forward in our examinations of the secret powers of creation."

Although a somewhat difficult subject to render in a popular manner, still it would not be proper to pass over unnoticed the *diffraction* and *interference* of light, as they present such strange phenomena, confirming the theory of undulations, and the abandonment of that of emission.

The beautiful colours by which thrifty housewives judge of the freshness of herring and mackerel, which are seen on the surface of water where a little oil has been dropped, are visible in crystals and spar, that paint the transparent soap-bubble, give richness to mother-of-pearl, and glisten on the wings of many insects, arise from the interference of the rays of light. This also is the exciting cause of what are termed Newton's coloured rings, which may be produced by procuring a flattish convex lens or a watch-glass, and piece of common glass. These being pressed steadily together when luminous, rings will be seen about the point of contact, of the same colour as the prismatic rays if the light be pure. They will be observed to be separated from each other by dark bands as the light diminishes from the middle of each of the rings. By using different coloured lights the result is different. In reflected light the point of contact is black, in transmitted bright; the rings luminous in reflected light are dark in transmitted light. On breathing on two plates of glass, and pressing them together, the prismatic colours are observable, but not separated by circular dark spaces, but by irregular black lines.

Place a lens l of short focus in a hole of a window-shutter, and allow a *pencil of light* horizontally to enter the dark room through a glass $g\,g$,

which will form a divergent cone; and that the light may more certainly

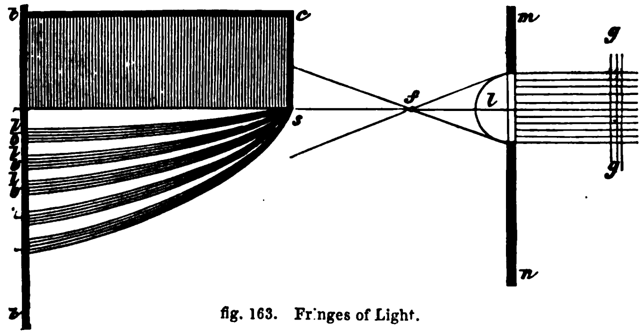


fig. 163. Fringes of Light.

be of the same nature, let it pass through coloured glass before entering the lens, which then will give but rays of one colour. Then at a short distance from the focus put up a screen *c s*, having an edge clear and thin, let the bottom of this be on an exact line with the focus of the lens; at a distance from the screen place a piece of ground glass *t t*, the top of which may be on a level with the top of the screen, and it must at least be twice the length of the screen.

Now on the light passing through the lens, a shadow of the screen is thrown on the ground glass; but on looking at it, this shadow, although it proceeds in a straight line from the focus and bottom of the screen to the ground glass, yet the lower part of the shadow is not dark, but a degree of brightness rises upward, from the line diminishing, however gradually, in intensity. Then below the focal line extended to the ground glass there are seen most extraordinary alternate fringes or bands of light and dark; a bright one *l* first, then a dark one *b*, and so on, both gradually decreasing in intensity as they descend, until the black ones become luminous, and are no longer visible. Then bands all start from the edge of the screen, and in descending to the ground glass each describe a hyperbole.

These bands may be shewn by all the tints of the spectrum; but if the red be commenced with, gradually as the tints descend to the violet, the fringes or bands lessen in width, and are closer together.

Now if a ray of white light pass through the lens under the same circumstances as above, that is, having a screen and ground glass, each colour of which white light is composed is diffracted, as if it were that only which was present. If we commence at the focal line on the ground glass, the violet fails first, and the red ought to come after the white fringe bordering the shadow; but at that part where the red fails when by itself, the other colours do not, there is a mixed tint. Therefore the rule by which the bands of individual colours are governed, being known by the order and nature of the tints given by white light, can be determined.

The presence of the lens to concentrate the rays is not at all necessary to this phenomenon; to shew this, we will suppose the arrangement to be, as shewn at fig. 164, only that at a short distance from the focus, a fine wire *w w* be placed in the course of the rays; the geometric shadow would then reach to *s s*, or the ground glass screen *t t*. Beyond this, on each side, *t s*, *s' t'*, fringes may be seen, resembling those arising from the edge of the screen in fig. 163, and are called *exterior fringes*; in addition to which

interior fringes occupy the whole width of the shadow, presenting with white light colours of various tints.

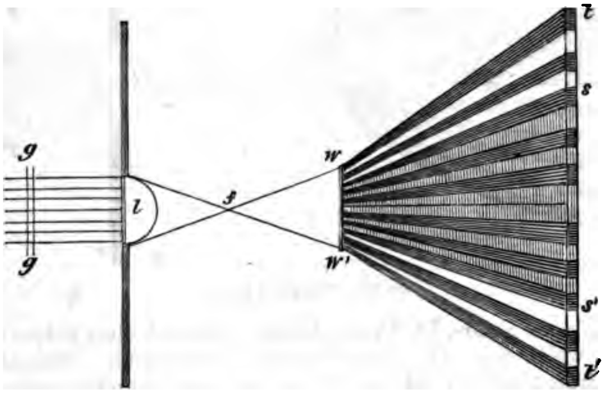


fig. 164. Fringes and Interference of Light.

Thus it is reasoned, that in particular circumstances rays of light have a mutual action upon each other; and from this action arises that extensive principle of interferences pervading the whole of the science of optics which clearly demonstrates the undulations of light.

The discoverer of the fringes, Grimaldi, stated that an illuminated body may become less bright by the addition of more light, arising from the interference and mutual action of rays of light; and this has been demonstrated in the following manner:

Solar light being admitted through two small lenses into a dark room, in such a way as that their diverging conical pencils mix at a certain distance, place a screen a little beyond the part where they mingle, and on looking at the illuminated part of the screen, there will be observed points that are partially darkened; these will vanish, and the circle become more vividly light, if one of the lenses be covered up; hence the loss of light causes a greater brilliancy.

When in this experiment only one colour of light is admitted, then the dark and bright fringes or bands are seen; but when only one lens is allowed to act, then the bands are no longer visible, and it is one decided light. Therefore by rays of light, coming from the same source, but by a different path, meeting rays of a similar nature obliquely, at a certain distance they appear to interfere with each other; and from their mutual action on coming to a point, almost destroy the brightness of the light.

The result of this discovery of interference is, that wherever light exists there exists motion; and this must be the motion of vibration "which," as a talented author observes, "constitutes the system of undulations; for the luminous substance would in this case undergo slight displacements, experiencing alternating motions, by which the luminous particle is at one instant removed from the sun, and in the next brought back by the same quantity; a vast number of these backward and forward motions occurring in a very short time. In this case the luminous substance would have an existence independent of the luminous body, just as the air has an existence independent of the sonorous body; this substance at *rest would not constitute* light, any more than air at rest constitutes sound."

The following simple phenomena arising from the diffraction of light are given by Peschel:

Suspend an opaque black ball in the sun's rays, and the presence of light in the shadow which it casts will be very perceptible.

Hold a bit of fine wire, or a needle, or any similar object, close to one eye, the other being closed, and look steadily at it against any light background, as a window or a candle, and you will see several needles.

If sun-light be admitted through a very narrow crack into an otherwise dark room, several cracks will be visible at some distance from the real one, separated by dark bands from each other.

Make a rectilinear incision, with a sharp penknife, in a piece of card-board. Look through the slit at the flame of a candle, and on each side of the real light others will be seen parallel to it, and marked with the spectral colours. This experiment may be rendered still more striking by looking through the slit in the card-board directly at a narrow cleft in the shutter, by which the sun's rays are admitted into a dark room.

Results similar as to colouring and extent, but of greater beauty, are obtained by making the light to pass through several apertures ranged close to one another.

Look at the flame of a candle through the thinnest part of a feather, and you will see several flames in a row; the brightness of their colouring will depend on the intensity of the light.

Look at any luminous point through a piece of fine cloth, and the light will be obviously inflected in a direction parallel to the texture of the material.

By the undulatory theory these phenomena are explained as consequent upon the interference of light; and that when the waves of light impinge on solid bodies, they are disposed to propagate new undulations, which start from these points of incidence, and by crossing each other's paths produce interference.

That majestic and glorious sign in the heavens the rainbow is caused by the refraction and division of the rays of light into their prismatic colours, by means of drops of rain which act as so many prisms. Rainbows can only be seen decorating the vault of heaven when rain is falling opposite to the sun and the eye; the violet is the colour of the inner arch, which is encircled by indigo, blue, green, yellow, orange, and finally by red,—in fact, is a large solar spectrum in the form of part of a circle. The red rays make an angle with the rays of the sun of 42° 2′, the violet rays 40° 17′, and the other coloured rays are between these; thus then the difference between 42° 2′ and 40° 7′ being 1° 45′, that must be the breadth of the rainbow. The inner or violet line forms part of a circle whose semi-diameter is 41°, and its situation varies according to the height of the sun: the higher the sun, the lower the rainbow.

If *c d* be two drops of water and *s s* rays of the sun incident upon each of them, those which enter near their centre will be refracted to a focus, as in a sphere of glass. At its point of emergence it is refracted a second time, and suffers the prismatic dispersion, when the red ray, as being the least refrangible, takes the lowest direction, and the violet, having the greatest refrangibility, takes the highest. If we suppose we have been speaking of the drop *c*, at a certain distance below it let *d* represent a

similar drop. The same refraction and production of the prismatic colours will happen in this second drop *d* as in *c*, and at some point *f* the red ray of the upper drop will intersect the violet ray of the lower. Suppose a spectator to stand so that his eye shall be at *f*, then from the upper drop he will see red light, from the lower one violet, and from the intervening drops between these two extremes he will see the intermediate prismatic colours, and consequently between *c* and *d* he will see a perfect spectrum.

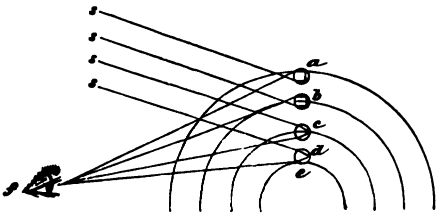


fig. 165.

In *a* and *b* the rays *s s* enter the drops of rain at the lower part, where they receive their first refraction, at the lower part of the back of the drops their first reflection, and at the upper part of the back their second reflection, and lastly, their second refraction and inverted prismatic dispersion at the points of emergence from the drops; in this case the violet ray, as being that portion of light which is most strongly refracted, takes the lowest path, and the red ray, as being the least so, takes the highest; this then is in inverse order to the drops *c d*. An eye, therefore, at *f* receiving the rays from *a* and *b* at their point of intersection, in the drop *a* will see the violet ray, and in *b* the red ray, and in the intervening rays between *a* and *b* the other prismatic colours, so that between *a* and *b* there will be a complete spectrum, whose lower extremity is red and the upper violet. This rainbow having a half diameter of 54°, it is sometimes observed without the other one, which only appears to a person on a plane when the sun is within 41° of the horizon. The rainbows above waterfalls, and the halos that sometimes surround the sun and the moon, are produced from the mist in the atmosphere, and are referred to the same principle as drops of rain creating the great and more intense rainbow which we have been describing.

A portion of a rainbow greater than a semicircle can only be seen when the observer is so situated as to have the sun below him; thus, for instance, if he be on a high mountain an arc becomes visible proportioned to his elevation; a complete circle of a rainbow may be seen in the spray of a cataract if the spectator be sufficiently elevated above the horizon. It will have struck the reader that each beholder sees a different rainbow, every drop of rain being viewed differently, or different drops only producing the beautiful vision according as the spectator may be situated.

We shall again have occasion to refer to the subject of lenses and the laws of refraction, that their peculiar properties may be understood when applied to the construction of various important optical instruments.

The diagram 166 shews that the image of an object will be larger or less than the object as its distance from a double-convex lens is greater or less. In this instance the arrow T M B is placed beyond the focus *f*, and rays from every part of it, as seen at T M B, pass through the lens L L, and are refracted and meet at the points *t m b;* those flowing from T meeting at a focus *t*, the rays from B at *b*, and those from the intermediate parts of T B at their different foci between *t b*. Now if we suppose the arrow *t b*

to be the object, the image T B will be seen of the increased size. When the distance between m C and M C are equal, then the arrow and its image will be equal to one another. But to obtain an image, the object must always be beyond f; for if it be not, the rays will not converge to a focus, but pass out of the lens parallel to one another; and if the object be nearer than the focus, then the rays will diverge away upwards and downwards, in both the last cases leaving no image whatever.

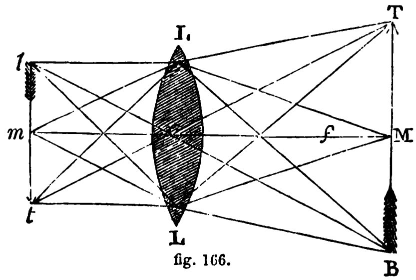


fig. 166.

Persons standing before a looking-glass see the figure of themselves apparently as far behind the glass as they are before it; this is from the ray having to travel from the person to the glass, then from the glass to the eye, and thus the distance is measured twice over, and the figure seems as far behind the glass as the figure in front is distant from it. Persons may see full-length figures of themselves in a glass which is not more than half the length of their bodies. Thus a young lady, A B, anxious to see the effects of a new dress, standing before the

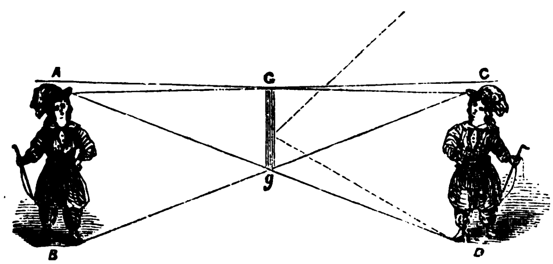


fig 167.

looking-glass G g, will see its suitableness at C D; for the ray passing from her eye falls perpendicularly on the mirror G g, and is reflected back in the same line to the eye, and has travelled through a distance equal to A G; but the ray proceeding from her feet B, which falls obliquely on the glass, will be reflected in the line g A to the eye; but as we view objects in the direction of the reflected rays which reach the eye, and the figure at the same distance behind the mirror as the person is before it, we must continue the line A g to D, and the line A G to C, where the figure is represented in the glass. The line g D is equal to g B or g A, and the line G g, which represents the length of the looking-glass, is half the line A B, which represents the height of the lady.

This is a subject usually proved by a simple theorem in geometry, and will be found fully explained in the *Illustrated Geometry*, to which we beg to refer the reader.

When we move backward from a looking-glass the figure seems to retire, and when we approach towards a glass the image seems to come forward; but with a velocity in both instances apparently twice that of your own movement, because the eye is affected with the motions both of the body and the image, which are equal and contrary.

Rays of light falling on glass pass through it, as we have shewn; but when a coating of mercury is applied to one of the surfaces, the rays are arrested and reflected; thus then, it is not the glass but the mercury that reflects the rays which form the image. Had mercury not been fluid, it would have formed a better mirror without the glass than with it. The finest glass manufactured is not perfectly transparent, nearly half the light being either absorbed or irregularly reflected from the inaccuracy of the polish; this accounts for the image never being so bright as the object.

Few persons think, when they look at and feel glass, that the surface possesses such an inequality as to make it reflect rays with considerable irregularity; but such being the case, opticians who have devoted themselves to the construction of superior astronomical instruments have experimented on various substances, and find a mixed metal, close in texture, little porous, and susceptible of a high polish, as best adapted for mirrors.

A concave mirror is formed of a portion of the internal surface of a hollow sphere; when parallel rays fall upon it, they are reflected, and converge to a point at half the distance of the surface of the mirror from the centre of its concavity.

If the three parallel rays A B, C O D, E F fall on the concave mirror G H, the middle ray will be reflected in a straight line D O C, as it is in the direction of the axis of the mirror. A B and E F falling obliquely on the mirror, are reflected obliquely to O. Then O D will be found to be equal to O C, or the half of C D. The dotted lines, it will be observed, exactly divide the angles of incidence and reflection, and the two oblique rays meeting at O make these angles equal. This, then, is the true focus at which parallel rays unite, for the more distant the rays the more obliquely they fall, the more obliquely are they reflected.

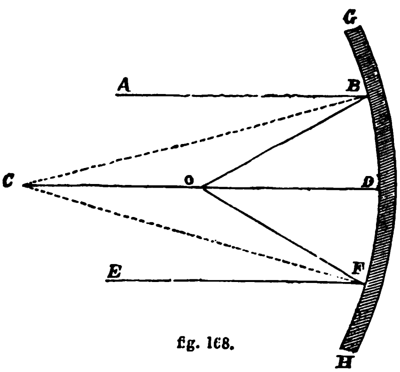


fig. 168.

When a concave mirror is turned opposite a celestial object, the rays proceeding from it are parallel to one another, and the image of the star, moon, or sun will be at O, halfway between the mirror and its centre of concavity; but the image will be an inverted one, as the rays cross each other. It is universally the case that the image formed by a mirror is inverted, if the rays after reflection converge to an actual focus. Thus W, fig. 169, is the concave mirror, I the candle, and G the image of the candle inverted.

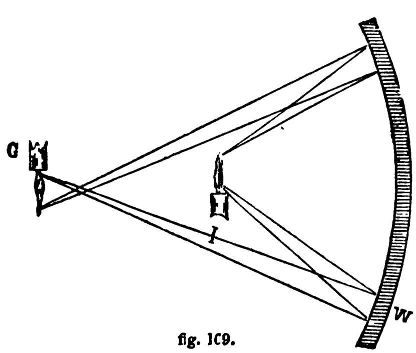


fig. 169.

If, however, the candle be moved nearer to the mirror than the centre of concavity, then the image will not only be erect, but also magnified.

The diagram, fig. 170, illustrates the different effects of convergent and divergent rays on a concave mirror. When rays fall convergent, they are sooner brought to a focus, as seen in the full lines; but when divergent as shewn in the dotted lines, the focus is at a greater distance than convergent or parallel rays.

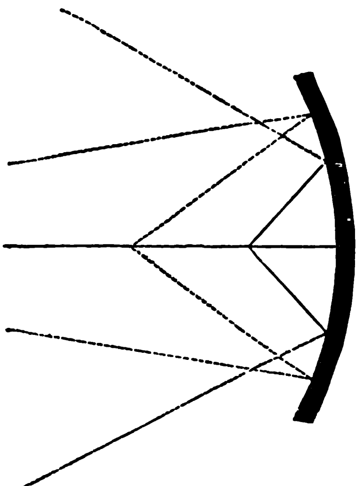


fig. 170.

A concave mirror may then simply be said to magnify, because the rays coming from an object and falling on the glass appear to the eye placed in conjugate focus to diverge to a great extent behind the glass when viewed in front.

A convex mirror is formed of the exterior surface of a sphere; and as the rays from it diverge, the images it produces are diminished. If three parallel rays *a b c* (fig. 171) fall on a convex mirror, *b* being at the axis, proceeds straight onward to *m* the centre of the sphere; but *a* and *c* falling obliquely, are reflected obliquely to *d e*; now as all things are seen in the direction of the reflected rays, the image presented by this mirror would be the same as if it was placed at *f*, the focus of a concave mirror of the same spherocity.

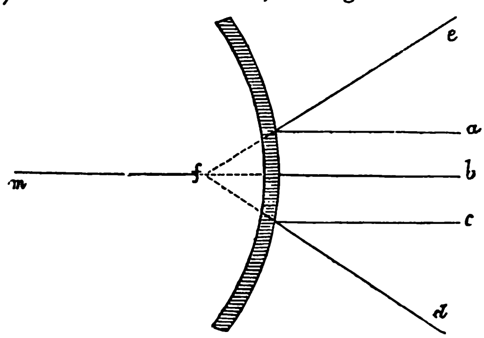


fig. 171.

A convex mirror diminishes the object, which invariably appears beyond the mirror, in its

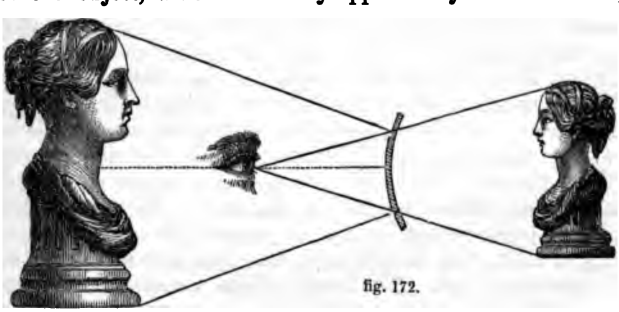


fig. 172.

natural position, smaller than the object itself: the further the object is

from the mirror, and the less the radius of the latter, the smaller will be the object, as in fig. 172.

An image thrown upon a mirror may, by employing more mirrors in an inclined position opposite each other, be multiplied many times and changed as often in every direction. To exhibit this there is an instrument made, and called the magic perspective: it consists of a tube having a division through the middle; and the experimenter being told to place a book or piece of board in this division so as completely to obstruct seeing direct to the end, then to hold a coin or any thing else at one end, and look through the other, the novice is surprised at distinctly seeing the coin, as he supposes, through the book or board.

Let *a b c d e f g h* be the perspective tube, and *b f c g* the opening in which the book or board is placed, *i* the eye, and *k* the coin. Then at *l*, *m* there is an opening into another tube *l n o m*; and at *l n o m*, are placed looking-glasses at angles of 45 degrees with the side of the tube, and the reflected ray proceeds in the course of the arrows, and the reflection of the image falling on *m* is again reflected to *o*, from *o* to *n*, from *n* to *l*, and from *l* to the eye, while all the time it appears to come in a straight line through the book.

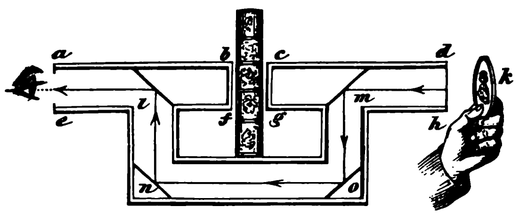


fig. 173.

A highly polished metallic concave mirror when exposed to the sun, on collecting the rays to a focus, so concentrates the heat that it is designated a burning mirror, and possesses the properties of a burning-glass. If a convex glass be placed in a hole of a shutter, and no other light than that passing through the lens be admitted, a picture of all the objects on the outside of the room will be seen in an inverted position on a paper placed in the focus of the convex glass, constituting a camera obscura or dark chamber.

This is truly the principle of the human eye, as will be afterwards seen. If a person take the eye of an ox that has been recently killed, and pare away the back of the eye until the black coat is arrived at, but without cutting that, then present the eye either to a single object or a variegated landscape, and observing the pared part, the whole will be seen beautifully pictured in an inverted position on the retina of the eye.

A portable camera obscura is made by having an oblong box in one end of which is fitted a smaller portion having a convex lens, and which part slides in or out to adjust the focus according to the distance of the external objects. At the opposite end of the box, at an angle of 45 degrees, a plane mirror *p i*, fig. 172, is fixed, which receives the image of the object from the lens *a*, and reflects it against a square of ground glass *j*. The picture there represented may be sketched on the rough glass, or if a piece of oiled paper be laid on it, a copy may be taken on it; but to do this effectually, a black cloth should cover the head and end of the camera to exclude extraneous light. The beauty of this instrument, the amusement to be derived from it, and the useful purposes to which it may be applied, deservedly make it a popular and favourite object of interest.

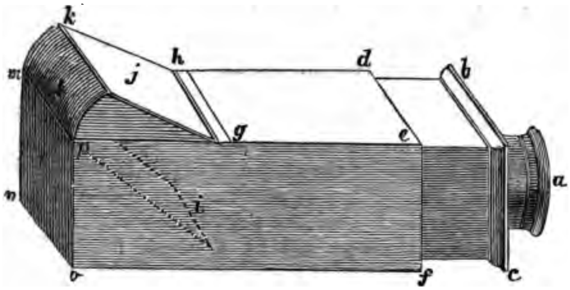


fig. 174.

The eye—that index of the soul, that channel of human knowledge—conjures up a host of feelings when the mind is directed to it as an object of special attention. The babe watches the rays of affection that beam from the maternal eye in sympathetic love and delight. The youth forms his ideas of those around him, and endeavours to divine truth in language, by watching the uncontrollable expression of the eye of those addressing the ear. The universal and irresistible feeling of reciprocal affection between the opposite sexes needs no other language than that expressed by the eye. Revenge and surprise, hatred and pity, joy and grief, all have distinctive and powerfully portrayed character in the eye. In infancy it is peered into as the symbol of the activity of the vital principle; in illness its look indicates the body's approach to health or accumulation of disease; while in age the glazing over of the eye announces the close of all mortal feelings, and the flight of the soul to the judgment-seat of the divine Contriver of the beauties and wonders of the organisation of man.

In its external appearance, what magnificence there is in the orb itself! sparkling as a diamond, the coloured parts varying in size with the amount of light; the exquisite little miniature of another being, or miles of variegated scenery pictured with a truthfulness belonging only to nature's pencil; a frame of bone protecting it from accidents; an arch of hair to ease a blow on the bone and turn the course of the "sweat of the brow;" then the eyelash catching the minute particles of dust, and the eyelids ever active in saving either from danger or injury the mirror underneath, and polishing and moistening the brilliant orb; while the motion of the adjoining parts is instigated by the emotions of the bosom, and give outwards signs of the secret and hidden feelings within.

The eye is the perfection of optical instruments, no effort of art being able to form a lens to refract the rays of light with the excellence of that possessed by the eye.

The globe-like object, fig. 175, is an enlarged representation of a section of the human eye a little above its usual size. Its mechanism is truly surprising and simple, formed of the parts described above as essential to the camera obscura. The strong covering *s s* is the part that appears white, and is

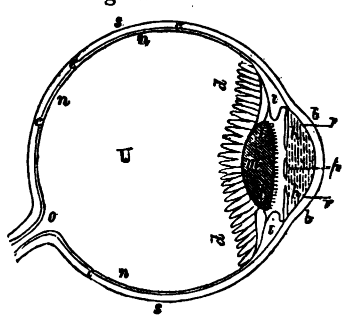


fig. 175.

named the sclerotica, or sclerotic coat, from its being a hard, tough, rigid and inelastic membrane of an interwoven fibrous texture. The window which admits the light is bowed out, *b b*, and called the cornea, from being, when dried, like fine horn, very transparent. In shape it is part of a segment of a smaller sphere than the eye-ball itself. Nearly the whole of the eye-ball is covered on its external surface by a highly vascular and delicate membrane known as the conjunctiva; it is strong, flexible, and close in its texture. The outer part of the cornea is convex and the inner concave, rather thicker in the middle than elsewhere. It consists of two or more layers, which are separated by a limpid fluid. This fluid increases the density, and thus adds to the optical effects of the eye; it acts as a lens on the rays of light entering it. The second membrane *c c* is the choroid, so named from the resemblance of its outer surface to the chorion, a membranous investment of the egg. It is a thin soft dark-brown structure, lining nearly the whole concave surface of the sclerotic, and terminates at *i i*. The purpose of this dark brown is to render the body of the eye a camera obscura or dark chamber. The colouring matter is called the pigmentum nigrum, from being of a dark colour in most animals. Just within the choroid is the central opening for the admission of light called the pupil *p*, and is bounded by a sharp well-defined circular edge; the pupil is surrounded by a coloured border of fibres called the iris *h h*, which acts as a curtain to admit more or less light on the pupil: when there is too much light the iris contracts, and when too little it dilates. It is the action of this part that is examined by medical men, as when not susceptible of the influence of light great danger is apprehended. It is the beautiful variety of colours here displayed that gives the character or name to eyes, and thus is derived its rainbow name of *iris*. The pupil, when expanded, will admit ten times the amount of light that it does when contracted. If we go from a light place into a moderately dark one, at first we cannot distinguish any thing; for the pupil being contracted, a sufficient quantity of rays of light cannot gain admittance, but as it dilates we gradually begin to perceive objects. If we go out of darkness into a glare of light the eye is pained; for the pupil being dilated, too much light rushes in before it is accommodated to the quantity. Behind the cornea is the aqueous humour *r r*, in which the iris and pupil are immersed; it resembles water, and is perfectly limpid, but holds in solution minute portions of several saline ingredients; behind this is the crystalline lens L *l*. It is formed like, and performs the offices of, a double-convex lens; but is not equal segments of spheres, the front being somewhat flatter than the back portion; it is the most refractive power in the eye. It is about the sixth of an inch in thickness, and about twice that in length. The substance is arranged somewhat like the coats of an onion, being divided into three sections, the cleavage planes of which diverge from the axis of the lens at angles of 120 degrees. In composition it resembles the white of egg, and coagulates when boiled. The lens is enclosed in a transparent and highly elastic membrane, marked by a black line *m*, which shuts in a very small quantity of fluid for the purpose of preserving it in its true and useful shape. Its important function is to refract the rays of light, which it does in a manner that is perfection itself, and causes a most beautiful and perfect image of external objects to be formed on the back part of the eye. Should *disease* produce an opacity of the lens, it is called cataract; and the sur-

geon, after extracting it, substitutes a double-convex lens in the shape of spectacles, and sight is regained. The space behind the lens is filled with a humour U, which having a supposed resemblance to melted glass is called vitreous. It is transparent, of a jelly-like consistency, and preserves the spherical shape of the eye. This part is called the posterior chamber of the eye, and that portion before the lens the anterior. The substantial coverings of the eye are for the preservation of that most important part, *nn*, the retina; the optic nerves enter the eye at *o*, and spreads out in the form of a fine transparent membrane over the whole of the concave surface of the posterior chamber, thereby forming the retina ; the outward portion of which seems like the matter composing the brain, and the inner part a most delicate web. It is on this that the images are thrown, and impressions received and conveyed to the brain.

The ciliary body *d d* is a thin, dark, annular band, like a frill of flat outspreading plaits, which encircle but do not reach the circumference of the lens. The front is attached to a ciliary ligament, and to a small portion of the back of the iris. This has recently been proved to be a muscular body, and exerts great influence over the movements of the iris. It is thickly coated and pervaded with pigment, except at the extremities of about seventy minute unattached points which fringe the inner margin, and radiate towards the lens like the florets of a marigold round its central disc; these are called the ciliary processes, and form a bordering around the window part of the eye.

We can see nothing but what is painted on the back of the retina of the eye; wonderful, then, must be the correctness and minuteness of the picture there impressed. But there is another fact which we have not yet noticed, which is, that every thing is there represented in an inverted position. The rays of light from the arrow *arw* (fig. 176) fall on the cornea of the eye, between *c* and *n*, and by passing through the pupil, lens, and humours, will converge to as many points on the retina, and there

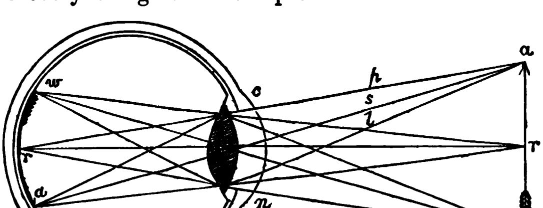


fig. 176.

forms a distinct inverted picture of the arrow *w r a;* because the pencil of rays *p s l* given off at *a* will converge to the point *a* on the retina, those from *r* to the point *r*, those from *w* to the point *w*, and the intermediate points in the same manner, by which means the perfect picture is formed, and the object visible. Now, here is the curious point, that although on the retina the picture is inverted, yet we see objects erect. No satisfactory explanation has yet been given of this phenomenon; some writers appear to think that it is the sense of feeling, which from earliest infancy we practise, that corrects the sense of sight, and leads us always to judge things in a reverse position to that on the eye. On this point, and also on another singularity in respect to the wonders of vision, Dr. Arnott offers the following philosophic remarks: "It is known that a man with wry-neck judges as correctly of the position of the objects around him as any other

person, never deeming them, for instance, inclined or crooked, because their images are inclined as regards the natural perpendicular of his retina; and that a bedridden person, obliged to keep the head upon the pillow, soon acquires the faculty of the person with wry-neck; and that boys who at play bend down to look backwards through their legs, although a little puzzled at first, because the usual position of the images on the retina is reversed, soon see as well in that way as in any other. It appears, therefore, that while the mind studies the form, colour, &c. of external objects in their images projected on the retina, it judges of their position by the direction in which the light comes from them towards the eye, no more deeming an object to be placed low because its image may be low in the eye, than a man in a room into which a sunbeam enters by a hole in the window-shutter, deems the sun low because its image is on the floor. A candle carried past a keyhole throws its light through to the opposite wall, so as to cause the luminous spot there to move in a direction the opposite of that in which the candle is carried; but a child is very young who has not learned to judge at once in such a case of the true motion of the candle by the opposite apparent motion of the image. A boatman, who, being accustomed to his oar, can direct its point against any object with great certainty, has long ceased to reflect, that to move the point of the oar in some one direction, his hand must move in the contrary direction. Now, the seeing things upright, by images which are inverted, is a phenomenon akin to those which we have reviewed."

"Another question somewhat allied to the last is, why, as we have two eyes, and there is an image of any object placed before them formed in each, why the object does not appear to us to be double? In answer to this, again, we need only to state the simple facts of the case. In the two eyes there are corresponding points, such that when a similar impression is made on both, the sensation or vision is single; but if the least disturbance of the position occur, the vision becomes double. And the eyes are so wonderfully associated, that from the earliest infancy they constantly move in perfect unison. By slightly pressing a finger on the ball of either eye, so as to prevent its following the motion of the other, there is immediately produced the double vision; and tumours about the eye often have the same effect. Persons who squint have always double vision; but they acquire the power of attending to the sensation of one eye at a time. Animals which have the eyes placed on opposite sides of the head, so that the two can never be directed to the same point, must have in a more remarkable degree the faculty of thus attending to one eye at a time."

"The corresponding points in the two eyes are equidistant and in similar directions from the centres of the retinæ, called the points of distinct vision, at which centres the imaginary lines named the axes of the eyes terminate; and it is worthy of remark that these points, in being both to the right or both to the left of the centres, must be one of them on the inside of the centre, as regards the nose, and the other on the outside. When the two eyes are directed to any object, their axes meet at it, and the centres of the two retinæ are opposite to it, and all the other points of the eyes have perfect mutual correspondence as regards that object, giving the sensation of single vision; but the images formed at the same time of an object nearer to or farther from the eye than the first supposed, cannot fall on

corresponding points; for an object nearer than where the axes meet would have its images on the outsides of the eyes, and an object more distant would have its images on the insides of the eyes, and in either case the vision would be double. Thus if a person hold the two forefingers in a line from his eyes, so that one may be more distant than the other, by then looking at the nearest, the more distant will appear double, and by looking at the more distant, the nearer will appear double."

"The reason of the term, 'point of distinct vision,' applied to the centre of the retina, is discovered at once by looking at a printed page, and observing that only the one letter to which the axis of the eye is directed is distinctly seen; so that although the whole page be depicted on the retina at once, the eye, in reading, directs its centre successively to every part."

We have given at length Dr. Arnott's theory of erect vision; for our own part, we had long believed that the optic nerves in their passage to the brain so crossed each other, that on their arrival there the nerve carrying the higher part of the inverted image placed it in a lower position, and that bearing the impression of the lower part deposited it in a higher part, and thus the image as impressed on the brain was in its erect position. This appears to coincide with the opinion expressed by Dr. Alison, who states, "that the harmony between the intimations acquired by sight and by touch, as the relative position of objects or their parts, notwithstanding that the impressions made by them on the external objects of sight and of touch are arranged inversely in regard to one another, arises from the course of the optic nerves and tractus optici, whereby impressions on the upper part of the retina are in fact impressions on the lower part of the optic lobes—that is to say, of the sensorium—and impressions on the outer part of the retina are, in like manner, on the inner part of the sensorium."

Dr. Alison also truly remarks, that if it were only by experience and association with the perceptions of touch that we learned that any object placed before the eyes, and seen by two images, is nevertheless single, we might reasonably conclude that we should never see an object double which we know by touch to be single; whereas we all know, that if by pressure on the ball of one eye, or by any other means, we direct the axes of the two eyes to different points in an object, we immediately see it double, and cannot by any means avoid seeing it double so long as that condition of the eyes continues, notwithstanding the full conviction, derived from touch, of its being single.

On this interesting subject many theories are advanced by those whose opinions deserve notice. Kepler considered that objects appeared erect, from the mind perceiving the impulse of a ray on the lower part of the retina, and he conceives this ray to be directed from a higher part of the object, and *vice versâ*.

Porterfield is of opinion, that the mind never sees the picture painted on the retina, and therefore never thus judges of the object; and that in seeing any object the mind, by virtue of a connate immutable law, traces back its own sensation from the sensorium to the retina, and from thence outwards, along right lines drawn perpendicularly from every point of the retina on which any impression is made by the rays forming the picture towards the object itself, by which means the mind always sees every point of the object, not in the sensorium or retina, but without the eye,

in these perpendicular lines. But these lines nearly coincide with the axes of the several pencils of rays that flow to the eye from the several points of the object; and since the mind has also the power of judging rightly of the distance of objects, it follows that every point of the object must appear and be seen in the place where it is; and, consequently, that the object must appear in its true erect position, notwithstanding its picture on the retina is inverted.

Reid and Brewster incline to this opinion; but Müller objects, he says, to the hypothesis that erect vision is the result of our perceiving, not the image on the retina, but the direction of the rays of light which produce it; involving an impossibility, since each point of the image is not formed by rays having one determinate direction, but by an entire cone of rays. And, moreover, vision can consist only in the perception of the state of the retina itself, and not of any thing lying in front of it in the external world. The hypothesis also that the retina has an *outward* action, and that objects are seen in the direction of decussating lines, that is to say, in the direction of the perpendicular of each point of the concavity of the retina, is a perfectly arbitrary assumption; since there is no apparent reason why one direction should have the preference rather than another; and each ultimate sensitive division of the retina, if it had the power of action beyond itself, would act in so many directions as radii might be drawn from it towards the exterior world.

The imperfection called short-sightedness is perceptible in the prominency of the cornea, and arises from the too great convexity of the cornea, or lens. Thus in fig. 177 it will be seen the rays are too much refracted, and brought to a focus before arriving at the retina, consequently the rays again spread, and the object is rendered indistinct. Persons so afflicted hold any thing they have to look at near to the eye, by which the rays falling on the crystalline humour are more divergent and do not so soon come to a focus. To lessen the defect, which is a serious inconvenience in crowded streets, concave lenses are fitted into frames, and then called spectacles; these are placed before the eye, and cause the perfect image to be formed farther from the lens in the eye, and hence not brought to a focus until it reaches the retina. The nearer an object is brought to a lens, the further the image recedes.

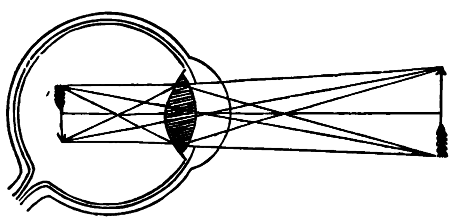


fig. 177.

Short-sighted people require concave lenses as in fig. 178, where the rays of light proceeding from *a*, pass through the lens *e e*, and are brought to a focus on the retina at *f*, as shewn by the dotted lines; whereas without the intervention of the lens *e e*, the rays would be brought to a focus at *d*.

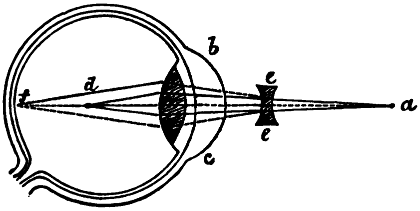


fig. 178.

Myopism, as it is generally called, is increased by using glasses more powerful than necessary. The eyes of such persons are mostly strong, that is, capable of great exercise in reading, writing, drawing, and other works dependent most particularly on eye-sight, and in which the lenses are not requisite; this in some respect recompenses them for the disagreeableness and disfigurement of perpetually wearing spectacles. This defect generally diminishes with years; and the person who in youth needed spectacles, in old age can see well without them.

Long sight is exactly the reverse of short sight, and in many instances equally annoying from not seeing near objects well. Thus in fig. 179 it is seen that the rays of light do not collect to a focus on the retina at *a b*, but do so at *c* behind it; and hence long-sighted persons hold an object at a distance from their eyes; for the more distant the object is from the crystalline lens, the nearer the image will be to it, and thus be brought to the proper position on the retina, whereby such persons can see distinctly. The auxiliaries of science to the long-sighted are convex lenses *e e* (fig. 180) fitted up as spectacles, which causing the rays of light proceeding from *a* to converge, are brought to a focus on the back of the retina at *f*, instead of passing as it were beyond it to *d*: the dotted lines shew the effect of the convex lens *e e*.

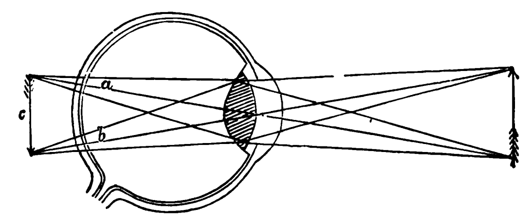


fig. 179.

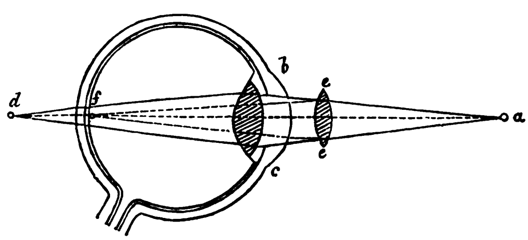


fig. 180.

These are not the only cases of defective vision arising from malconformation of the cornea; they are much more common than has been supposed, and it is said that few eyes are free from them. One eye may be alone affected; and a most remarkable and instructive instance of this defect has been adduced in the person of the astronomer royal, Professor Airy. In his case it arose from a defect in the figures of the cornea and lens: he ascertained the eye to refract the rays to a nearer focus in a vertical than in a horizontal plane, which rendered the eye utterly useless to him, and a serious impediment to his astronomical investigations. To correct this, after much thought, Professor Airy himself contrived to have made a double-concave lens, in which one surface was spherical, and the other cylindrical. The use of the spherical surface was for the purpose of correcting the general defect of the too-convex cornea. And in his own words: "After some ineffectual applications to different workmen, I at last procured a lens to these dimensions: radius of the spherical surface $3\frac{1}{2}$ inches, of the cylindrical $4\frac{1}{2}$, from Mr. Fuller of Ipswich. I can now

read the smallest print at a considerable distance with the left—the defective—eye as well as the right. I have found that vision is most distinct when the cylindrical surface is turned from the eye; and as, when the lens is distant from the eye, it alters the apparent figure of objects by refracting differently the rays in different planes, I judged it proper to have the frame of my spectacles made so as to bring the glass pretty close to the eye. With these precautions, I find that the eye, which I once feared would become quite useless, can be used in almost every respect as well as the other."

The focal centre of the eye is generally admitted to be at a very little distance behind the crystalline lens, and the angle formed by the intersecting axial rays from the two eyes is called the *visual angle*. In looking steadily at an object with both eyes, it has to be brought into the focal centre of the produced visual axis, and in doing this the eye revolves round a point which is the *focal centre*. The motion is accomplished by the reciprocal sympathy of the muscles of each eye mutually acting together.

The eye, on seeing a landscape, does not take in all the points at the same time; but so rapidly does it move, that by the retention of points on the retina, the picture seems a whole, and the mind receives it as if all was seen at the same instant. Hence it is believed that we only see perfectly the particular points of an object when the axis of the eye is in a direct line with it. Dr. Young states, that by fixing the eye steadily in its usual position, a little forward and downward, and moving a luminous object, the range of vision upwards is 50°, downwards 70°, inwards 60°, and outwards 90°; that is, a horizontal play of 150°, and a vertical play of 120°. But of course different eyes vary in their powers.

If a person look down upon a human eye immersed in water, as may be tried when bathing, the iris will be seen shining brightly inside the eye, while the cornea will seem to have disappeared, and water penetrated the eye. The illusion is so strong as to alarm the person who gazes on an eye so situated, from its unnatural appearance. The diver, when he looks upwards, sees things as if through a small round hole; but all objects are visible, those near the horizon distorted, and contracted as to height.

If we gaze at the bright sun, and then close our eyes, various colours are seen before the form of the object disappears. Sir Isaac Newton experimented on this subject, and wrote an account of it to Locke. He describes first looking at the sun, and then seeing the visionary appearance afterwards. "At length," says he, "by repeating this, without looking any more at the sun, I made such an impression on my eye, that if I looked upon the clouds, or book, or any bright object, I saw before it a round bright spot like the sun; and, what is still stranger, though I looked upon the sun with my right eye only, and not with my left, yet my fancy began to make an impression upon my left eye as well as upon my right; for if I shut my right eye, and looked upon a book or a cloud with my left eye, I could see the spectrum of the sun almost as plain as with my right eye, if I did but intend my fancy a little while upon it; for at first, if I shut my right eye, and looked with my left, the spectrum of the sun did not appear till I intended my fancy upon it; but by repeating this it appeared every time more easily. And now, in a few hours' time I had brought my eyes to such a pass, that I could look on no bright object with either eye, but I saw the sun before me, so that I durst neither write nor read; but to recover the use of my eyes, shut myself up in my chamber

made dark for three days together, and used all means to direct my imagination from the sun; for if I thought upon him, I presently saw his picture, though I was in the dark; but by keeping in the dark, and employing my mind upon other things, I began in three or four days to have some use of my eyes again, and by forbearing to look upon bright objects, recovered them pretty well, though not so well but that, for some months after, the spectrum of the sun began to return as often as I began to meditate on the phenomena, even though I lay in bed at midnight with my curtains drawn."

What amazing adaptation has the eye to circumstances affecting it, when we have the power of reading by the light of the full moon and the noonday sun, the difference of their intensities being as one to three hundred thousand!

Our perception of objects arises from the impressions on the retina being communicated by the optic nerve to the brain, where they are what we call recognised by the mind; thus, we do not see the objects painted on the retina, as we would need another eye to do so. When the nerve is diseased or injured, the retina may receive the image, but the mind no longer is susceptible of the impression. When the brain is disordered the optic nerve sympathises so much, that, without the retina having such an object upon it, there is presented to the mind those singular delusions cleverly described in the *Philosophy of Apparitions;* while in fever, and the gradual decay of the healthy state of the nerves on the bed of death, there arise those remarkable delusions, painful to those who listen to their description, but seemingly often a source of delight to the sufferer.

One of the sublime provisions with which the eye is gifted is the duration of the impressions on the retina, so that we are enabled in the frequent flashing of the eyelids over the eye never to lose sight of the object engaging our attention.

There are several conditions necessary to convey the impression of the object to the optic nerve, and from thence to the brain. Of these one is a certain length of time for light to excite the impression, which, after doing so, is retained after the cause has ceased. M. D'Arcy found that when a live coal was swung round in a circle 165 feet distance, the impression remained on the retina a little above the seventh part of a second. But the duration of the impression depends on the colour of the light, for white remains longest, next yellow, then red, and blue the shortest period. Taking the average length of time for the duration of the impression by all the colours, from the instant of their maximum intensity till their disappearance, it is found to be one-third of a second in a dark room, and one-sixth of a second in a light room. If two or more impressions succeed each other at such short intervals that the first has not faded away before the next commences, they run into each other, the eye seeming to receive them as if they were but one impression, as we know when we whirl round a piece of burning stick, which seems like a perfect circle of fire. Fireworks act in the same manner, and lightning appears as a stream of light. The retina must also be exposed to the influence of an object before it can be visible: thus the flight of a musket-ball being too rapid to cause an impression, it is not seen; again, if the luminous impression be too weak, the object cannot be discerned.

In using a lens those rays that fall upon it at a distance from the axis intersect those that fall upon it nearer to the axis, and consequently, on

being refracted nearer the lens than the principal focus, indistinctness is created, which is called the effects of spherical aberration; this in lenses is remedied by covering the rims, or part of their surfaces, by some substance which is not transparent, so that the rays pass through only that part, where, on meeting after refraction, they will be at one point. In the eye this indistinctness is provided against by the shape of the crystalline humour, the place of the iris, which also covers up a portion of the lens, and by the concavity of the retina, all combining most wonderfully to effect the desired object, and perfection of vision.

We know that in an artificial convex lens it is limited in its power, according to distance, of shewing distinct images, yet, resembling it as it does, the human eye has a beautiful muscular adaptation by which distant as well as near objects may be instantaneously seen in a most distinct manner; a power of self-adjustment, although limited, yet most important to our happiness and preservation of life.

Even acromatic object-glasses are so far imperfect, that they do not bring the *chemical* rays of light to the same focus as the *luminous* rays. There is likewise another property termed *latent* light, or the influence and principle of light in darkness. The continuating rays of light are those that would appear to prolong the disturbance of the surface of a body once set up or begun. The yellow are the continuating rays: by means of these, photographists are enabled to develope an invisible image when the change has been once begun or set up on the chemically prepared surface. The experiment by Moser will more clearly explain this, see the article on Photography.

This curious property of the yellow rays of light may afford us some clue to the use of the yellow spot in the central region of the retina, known as the yellow spot of Sœmmering, not far removed from the optic nerve itself, but where the light as it enters the eye is first received: we may therefore suppose the retention of the impressions to be stronger here, owing to the continuating power of this yellow spot. It is quite certain that the retina at this very spot is more sensitive than elsewhere, which no doubt arises from the luminous rays acting more energetically upon it.

Here we have a curious and important physiological inquiry, affording some explanation of the indelible fixed impress received with the rapidity of an electric flash, and hence conveyed to the mind, to be there reproduced at will with the same vividness years after the first momentary impression was received upon the retina.

There is another remarkable fact which ought not to escape mention, that at the spot where the optic nerve enters the eye it is totally insensible to the stimulus of light; for this reason it is called the *blind spot*. The fact is, that at this point the nerve is not yet divided into those almost infinitely minute fibres, which are fine enough to be either thrown into tremors or otherwise changed in their mechanical, chemical, or other state, by a stimulus so delicate as the rays of light. A simple and curious experiment will at once prove its existence. On a sheet of black paper or other dark ground place two white wafers, having their centres three inches distant. Vertically above that to the *left* hold the *right* eye at twelve inches from it, and so that, when looking down on it, the line joining the two eyes shall be parallel to that joining the centre of the wafers. In this situation closing the left eye, and looking full with the right at the wafer perpendicularly below it, this only is seen, the other being com-

pletely invisible. But if removed ever so little from its place, either to the right or left, above or below, it becomes immediately visible, and starts as it were into existence. It will cease to be thought singular, that this fact of the absolute invisibility of objects in a certain point of the field of view of each eye, should be one of which scarcely one person in a thousand is apprised, since it is well known to medical men that persons have been totally blind with one eye without their being at all aware of the fact.

We judge the dimensions of objects, that is, their real from their apparent magnitude, by the angle under which its rays intersect each other in the eye, aided by its distance, position, and motions, which our judgment draws conclusions from by continued exercise, commencing in earliest infancy, assisted by experience in after life. We infer the size of distant objects from the decrease of the visual angle, as well as the relative distances of objects from each other by the angle of vision varying at each point. The apparent or linear magnitude must be of a certain size to produce an image on the retina, besides an illuminating power and colour. The image of an object moderately illuminated must be 0·001 of an inch long, or the extreme rays of light must form an angle of half a minute in the eye at a minimum; whence it follows that an object of mean illuminating power will be visible if its distance from us is not more than 68,000 or 69,000 times its greatest length. Strongly luminous bodies, such as the fixed stars, are visible at infinitely small visual angles; they excite in the eye merely a sensation of light, without creating any impression as to their apparent magnitude or even form.

Plateau asserts that white may be distinctly seen in the light of the sun at an angle of 12″, yellow at one of 13″, red at 23″, and blue at 26′; but that in ordinary daylight these angles must be half as large again.

We judge of the motions of bodies by their images moving on the retina; but to be able to detect motion, the line of vision must describe at the least one degree in each minute of time: this not being the case with the heavenly bodies, their motions are imperceptible. The nearer the direction of the motion is at right angles to the line of vision, the greater will be the apparent motion produced by any real movement of an object. The hour-hand on a clock stealing stealthily along is not perceptible, from having less motion than that stated above.

At the first glance at the subject of single vision, it seems strange with two eyes, having each an impression of an object on the retina, that we do not see the object double. But the beautiful mechanism of the muscles that move the eyes act in such perfect unison, that the axes of the eyes converge towards the object to which they are adjusted, and the image falls exactly on the same parts of the two retinæ.

If *a b* be the two eyes, and *c* the object before them, *a c*, *b c* are the axes that meet in *c*, therefore an image is produced in each eye which will correspond with the perspective projection of the object from the points *a* and *b*. But if the eyes be set so that their axes meet either before or beyond the object, then we see the object double. Thus, if a candle be at a distance of about ten feet, we see it distinctly as one object; but if we place a finger,

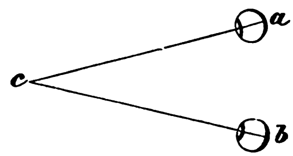


fig. 181.

F, fig. 182, at about ten inches from the eyes, and look steadily up it, then a candle, D D, will be seen on both sides of the finger. This arises from the

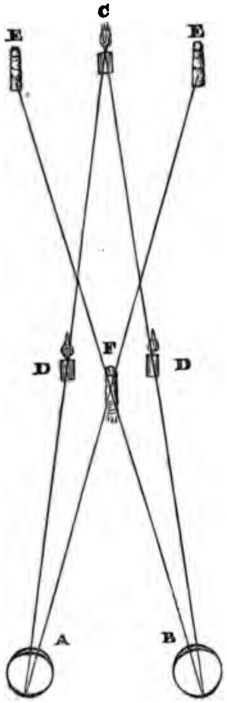


fig. 182.

axes of the eyes meeting at the finger, and their crossing one another; then the rays from the light passing on each side of the finger produce two images of the candle on the retinæ. But if the optic axes be directed to the light C, then the finger will be seen double, E E, on each side of the light.

Should, however, the object be brought so close to the eyes that the optic axes converge, then the perspective projections of the object are seen differently by each eye, and increase in difference the nearer the object is brought towards the eyes from the greater convergence of the optic axes. Thus, when we place an object within two or three inches of the eyes, and look at it first with one eye and then with another, the head being kept in the same position, the perspective projections will seem to be different; we thus compel the eyes to converge to the degree of squinting, whilst with distant objects they are nearly parallel. The quality of focal change becomes of more value and importance in cases where the sight of one eye is lost. A person suddenly deprived of the use of one eye estimates with the greatest difficulty the distance of objects. It would be almost impossible to snuff a candle with one eye closed, or even to place the finger exactly on any fixed point. The single eye, like the single leg of a compass, cannot at first measure distance; but, after some time, experience teaches the one eye to estimate distance by the change of focus alone, whilst with both eyes we feel and measure distance by the convergence and divergence of the visual axis. This remarkable phenomenon engaged the attention of Professor Wheatstone, who, on the 21st of June, 1838, read a paper at the Royal Society "on some previously unobserved phenomena of binocular vision" (sight with two eyes); in the course of which he described an instrument, the *Stereoscope*, invented by himself, by which two perspective diagrams of the same solid were seen at one view as completely solid as the object itself.

In 1839 Mr. Wheatstone brought his discovery before the British Association, at Newcastle, where it gave rise to a discussion of great interest, in which Sir D. Brewster and Professor Whewell took part; and Sir John Herschel characterised the discovery "as one of the most curious and beautiful for its simplicity in the entire range of experimental optics."

In Germany the subject excited still more interest, and was at once eagerly taken up. The new light thrown on the subject of double vision engaged the attention of the most able physiologists and metaphysicians—Bruccke, Volkman, Morer, Tourtual; and in Geneva Mr. Prevost wrote on the subject.

In the commencement of 1839, the photographic art, upon which Niepce, Talbot, and Daguerre had long been at work, was discovered; and Mr. Talbot and Mr. Collen in the same year, at Mr. Wheatstone's request,

prepared photographs of full sized statues, buildings, and portraits, for the stereoscope.

Mr. Wheatstone's diagrams were proof that small drawings may be made to represent under the stereoscope the complete effect of reality. Two miniatures might be painted, each with one eye, if the artist could attain sufficient accuracy, which, seen by the stereoscope, would be seen as one, and round as life.

These, however, were only illustrations of an important addition to science. A new step was gained in explanation of the phenomenon of sight. It was clear that the inner eye (if we may use the phrase) was furnished with two outer eyes, not merely for the uniformity of the face, nor to puzzle philosophers, but to present an instantaneous perfect vision of the form and position of objects. The one eye, in fact, seeing round one side, the other eye round the other side, and the inner eye having thus brought before it in one and in full solidity the whole object.

fig. 183. Reflecting Stereoscope.

The form of the stereoscope as originally produced by Professor Wheatstone, and which he called the reflecting stereoscope, is shewn in fig. 183; and it is on many accounts the most convenient form, as it allows of every adjustment, and can shew pictures of any size. A reflecting stereoscope may be readily constructed, and, as a philosophical toy, will afford perhaps more amusement, and certainly excite more astonishment, than the well-known kaleidoscope. It simply consists of two pieces of looking glass set at right angles to each other in the centre part of the instrument. The objects or designs are slid into a groove at the internal ends of the instrument, which are at a few inches distance from the reflecting mirrors, care being taken to place each design in its proper position. For small daguerreotypes, the

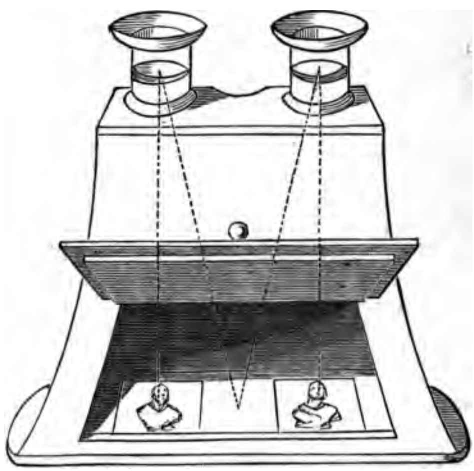


fig. 184. Refracting Stereoscope.

refracting or prismatic stereoscope (also constructed by Mr. Wheatstone) is better adapted. Several ingenious modifications of the instrument have been made by Professor Dove and Sir David Brewster. The latter, which is most generally in use, has the appearance of a double opera-glass; and the modification consists in the substitution of quarter lenses for the prisms employed by Mr. Wheatstone; the eye-glasses refract, or, in other words, throw the images out of the direct line to the centre between the eyes; and each image being in this way removed in a direction towards each other combine, and thus produce the effect of solidity.

The engravings of the bust (fig. 184) imperfectly shew the small difference in perspective necessary to produce the effect of solidity. They are intended to represent a pair of photographic pictures, by M. Claudet, which seen through the stereoscope, have in every respect the appearance of the original bust.

The diagrams of several forms of crystals and geometric solids are illustrations which may be observed without any instrument, to the no small amusement of those who for the first time see them, and may be multiplied in almost infinite variety. These diagrams are constructed to represent what may be termed right and left eye views of objects, as we should actually see them with the left or right eye alternately. Take, for example, the railway tunnels (fig. 185), and squint at them: three pictures will present them-

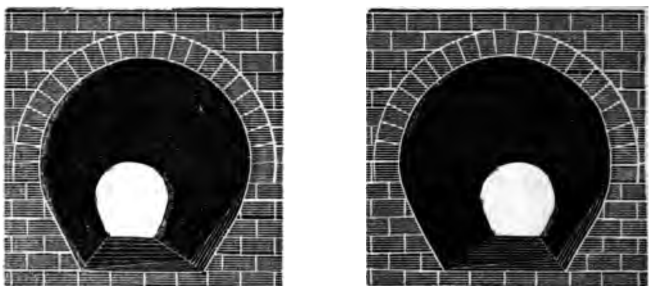


fig. 185. Railway Tunnel.

selves, the central one being a combination of the other two, and producing the effect of a perfectly hollow tunnel; in like manner the other diagrams will combine to form an apparently perfect solid body, presenting all the appearance of a network standing out from the paper. In this case, what is done by the aid of Mr. Wheatstone's instrument, is simply effected by crossing the vision, or squinting. It greatly facilitates the squinting to place the point of a needle held in the hand before the picture, and whilst the eyes continue to regard the needle-point, to move it towards the eyes until the pictures coalesce, when three images will be seen, and the middle one, which is the only one seen at once by the two eyes, will have the solid appearance we have described. Some little inconvenience may be experienced at first in getting this curious and remarkable phenomenon, but a little patience and perseverance will overcome the difficulty, and will be well rewarded by the result. Our artistic and scientific readers, when they clearly understand the theory of this beautiful discovery, will be enabled to produce any variety of subjects; for the regular bodies, all that is requisite is to make one drawing, and simply take a reversed transfer. On using any of the drawings we have given, or copies of them for the

reflecting instrument, the left design must be placed in the right, and the right design at the left end. The idea of solidity is evidently produced by the combination of two pictures of a solid body taken from either eye, as from two different points of sight. The perception of distance or perspective Mr. Wheatstone attributes to the same cause; which explains the fact that all paintings and drawings are, in reality, but pictures for one eye, and are seen most like reality when they are looked at with one eye only. We may have distance, dimness, difference of light and shade, but cannot have real roundness and space between and beyond objects, unless each eye has its picture. As it is, our paintings may be said to be a one-sided or one-eyed perspective—the whole landscape or portrait as it would appear to the two eyes is not shewn.

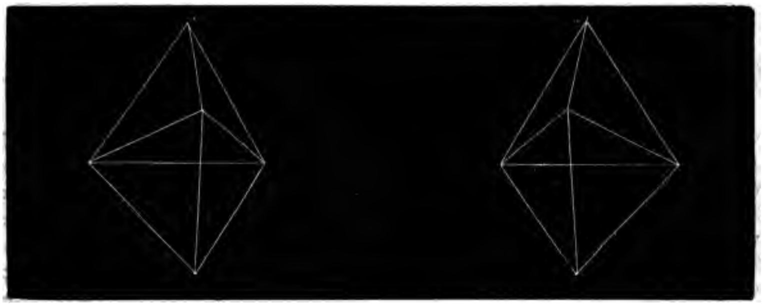


fig. 186. Double tetrahedron, the sides being equilateral triangles.

So long as mere drawings by hand were used, it might be held that the effect, however wonderful, was but some trick of art by which the senses were cheated. The daguerreotype, however, admits of no trick; the silvered plate has neither line, nor light, nor shade, but such as the sun gives it: the two plates in the two cameras stand truly for the two eyes,

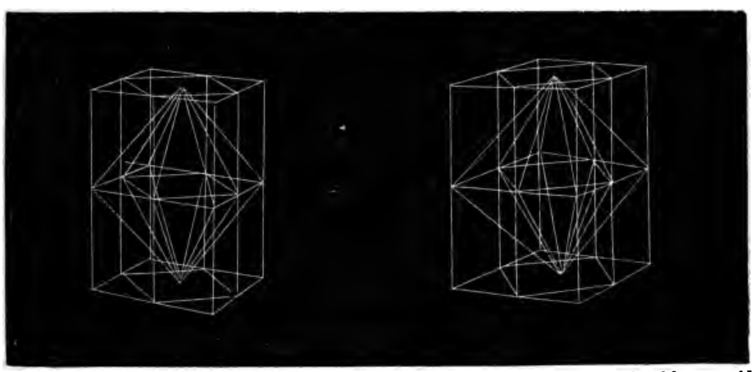


fig. 187. Square prisms, and octohedrons with square bases—the forms of the crystals of ferrocyanide of potassium, bicyanide of mercury, idocrase, and anatase.

and receive each just such a picture, no more, no less, as each eye receives. There is, therefore, no further room for doubt as to the need for two eyes; we have taken by the aid of photography the very picture from each, and have made them tell their secret. Our double vision is but perfect vision.

It will be said that persons with one eye nevertheless see distinctly, and see perspective and rotundity. They do so; and there is neither difficulty in the answer, nor any refutation in the fact of what we have said as to double vision. One eye alone judges of the relief of an object, from the accustomed distributions of light and shade, giving perspective appearances, though the perceptions it hence acquires are less vivid than those

fig. 188. The regular tetrahedron—the form of crystals of copper, nickel, gold, alum, common salt, arsenious acid, fluor spar, and iron pyrites.

obtained by means of two eyes. Another curious fact is, that a one-eyed person when looking at a solid object is constantly changing the position of the head from side to side: the result of this is, that he is by this means getting the same effect with one eye that is produced by two eyes with the head stationary. With two eyes, as we have before stated, two images from different points of sight are combined to produce solidity; with one eye, and a constant change of its position, two images in like manner are produced; but the combination depends on the curious circumstance of the second impression falling on the retina before the previous impression has escaped. The retention of objects on the retina some time after their removal has been before explained; therefore a one-eyed person, with the stereoscope, by first looking through one side and then through the other, gets the effect of distance and solidity simply by the retention of the first picture on the retina.

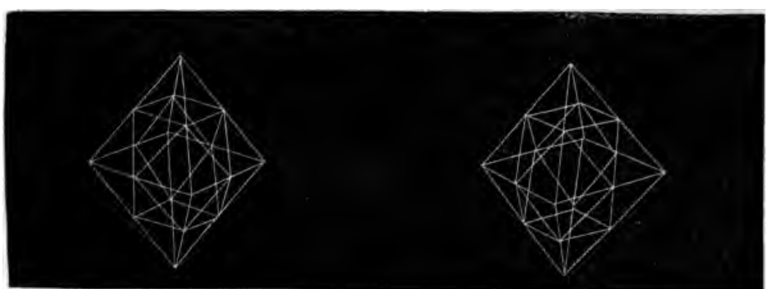


fig. 189. The natural crystal of the topaz with cleavage at right angles to its three axes.

There is another point which needs explanation as to the stereoscope pictures. They shew not only solidity in single objects, but in perspective. M. Claudet has a number of views of the interior of the Great Exhibition of 1851, and though but about $2\frac{1}{2}$ inches square, the vast extent of the building, every column, girder, and article exhibited, can be seen standing out

in its place, and with asperfect solidity and distinctness as did the true Crystal Palace and the objects themselves; it seems no picture, but a model, inimitable in its wonderful accuracy and comprehensiveness of detail. But it will be said that our explanation cannot be true as to distant objects, for that in their case both eyes really see the same picture; and yet the views of the Exhibition seen in the stereoscope have the distant objects in equal roundness and relief with those nearer at hand. This is owing to the fact, that in this instance the daguerreotype shews us a view as if the pictures were taken from a small model of the building brought sufficiently near for the whole to be within the distance influenced by the angle of the eyes. In fact, instead of seeing the object itself, you see a miniature model of it brought close to the eyes; so that, in this instance, the stereoscopic daguerreotypes actually surpass the reality.

The complete perspective of distant portions of the picture in the stereoscope is not perceived to perfection until it has been looked at for some seconds, though the near portions are seen in their full roundness and solidity at once. This arises from the instrument not being perfectly adjusted to the eyes of the observer, whilst it requires for instantaneous perfect vision a different adjustment for different persons. On attentive observation it may also be noted that the near and distant objects do not appear single at the same instant. This arises from the fact, that whilst the near objects are seen by each eye at a certain angle, and so that the two pictures form one, the distant objects, with eyes placed at the same angle, are more or less separated, and so are seen more or less distinctly as two pictures. To correct this the eyes alter their distance from each other, and it is only when they have done so with accuracy, that the distant portions of the picture are brought to coincide, that the roundness of the farthest portions is seen as distinctly as that of the nearest. This process of adjustment of their two pictures, both as to real object and their daguerreotypes, the eyes are incessantly at work upon.

These stereoscope pictures are not only curious, they are beautiful and useful. We may have, in future, galleries of portraits no fictions of painters, but the people as they were—not flat and framed, and hung along the walls, nor in cold marble, but round and real as the originals looked in life: and so with buildings and scenery; we may have, at a cheap rate, our hall of antiquities—Pompeii as it is, Nineveh as Layard sees it—scenery in foreign lands, in our own, in all the minuteness, grandeur, and beauty of nature. Neither Claude nor Turner could have given more than half such physical or aërial perspective. The artist may carry in his stereoscope the immortal works of the genius-inspiring masters of every age and country; and wherever the highest living beauty is to be found, he may have in an instant his models, subject to no errors of his pencil, but in all the full rich roundness of reality.

A simple and cheaply-constructed stereoscope, for viewing the diagrams of crystals given in these pages, may be made by taking an old convex spectacle-glass, dividing it in the centre by cutting it with a diamond, then again fixing the two pieces into the metal frame, with the thin side placed at the inner corner that is nearest the nose; they then will be made to form a prism, which is all that is required to make an instrument of this kind.

Another wonder of binocular or two-eyed vision is Professor Wheatstone's pseudoscope, an instrument so called on account of its giving false perceptions of all external objects. Some of the illusions are very extraordinary. Its effect may be briefly expressed as making whatever point is nearest seem farthest off, and the reverse; so that all objects seen through it appear as if they were turned inside out. A solid terrestrial globe is seen concave, like Wyld's globe, with the map on the inside. The inside of a tea-cup appears a rounded projecting solid. A China vase, with embossed coloured flowers, appears as if it were cut in two; the side with the flowers being indented. A bust shews as a deep hollow mask. Other more complicated, and in some cases perplexing, illusions are produced by the instrument, which is very portable, and will, from the infinity of its illusions, even as a toy, become popular.

THE TELESCOPE.

By the invention of the telescope man may almost be said to have created another sense, for with it he rent asunder the veil bounding his knowledge of the universe, and peered into space hitherto hidden from his unaided vision. By the telescope he gained insight into the beautiful, simple, and undeviating laws of creation; he beheld the sublime immensity of the Almighty's works, and by comparison the insignificance of the atom on which man proudly trod, and arrogantly had assumed as the chief of nature's productions. The telescope has taught humility to man —has shewn that his mind cannot grasp the extent and wonders of the works of God in boundless space—and that his duty is to adore that Power which is beyond his understanding.

The word 'telescope' is derived from the Greek, and means to see afar off.

The telescope is said to have been discovered by some children when at play in a Dutch spectacle-maker's shop; others state that Zacharias Jansen, a spectacle-maker of Magdeburg, trying the effects of a convex and concave glass united, found, that when placed at a certain distance from each other, they had the property of making distant objects appear near to the eye: however this may be, the first application of it to the purposes of science was by the celebrated Galileo.

The telescope consists of a long tube painted black in the inside to absorb superabundant light, and containing certain lenses. That which bears the name of Galileo's telescope consists of a convex object-glass *a b*, and a

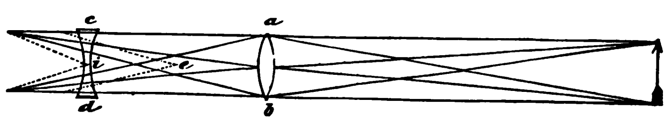


fig. 190.

concave eye-glass *c d*. The distance between the two lenses is less than the focal distance of the object-glass, but the concave glass is situated so as to make the rays of each pencil fall parallel upon the eye, as is evident by conceiving the rays to go back again through the eye-glass towards *e*, *i e* being the focal length of the eye-glass. When the sphere of concavity

in the eye-glass of a Galilean telescope is equal to the sphere of convexity in the eye-glass of another telescope, their magnifying power is the same; but the concave glass being placed between the object-glass and its focus, the Galilean telescope will be shorter than the other by twice the focal length of the eye-glass. Hence, if the lengths of the telescopes be the same, the Galilean will have the greatest magnifying power. It will be seen the eye-glass receives the convergent rays before they meet and form the image, and by refracting them makes the rays diverge, and the object is seen at *e*.

This is an extremely simple instrument, and from its portability used as a pocket telescope; when constructed on a small scale it is called an opera-glass. It possesses but a limited field from the dispersion of the light by the concave eye-glass, and has not a great magnifying power; yet it affords a distinct and clear view of objects, enlarging their proportions, and hence is used in observing objects on the surface of the earth.

To obtain a great magnifying power and a just proportion of the objects, "ærial" telescopes, frequently more than one hundred feet long, were at one time used. The object-lens was fixed on a pole in a frame, and moved by means of a string or wire; no tube was used excepting to hold the object-glass, with proper arrangements for its movement.

The size of an object-glass does not add to the magnifying power, but merely to the brilliancy of the image from the greater number of rays diverging from it. But by using two plano-convex lenses, so combined as to be like one glass, the magnifying power and field of view are increased.

The astronomical telescope differs from the Galilean in having a convex eye-glass, by which the magnifying power is increased. The two lenses N S and L E are placed at the opposite end of two tubes, the one sliding within another, fig. 191; the former of which is called the *object-glass*, from being next the object A B, and the latter the *eye-glass*, from its being next the eye, placed at I: the lenses are of unequal focal length, but so fixed that they have a common axis. A B is the object supposed to be at a great

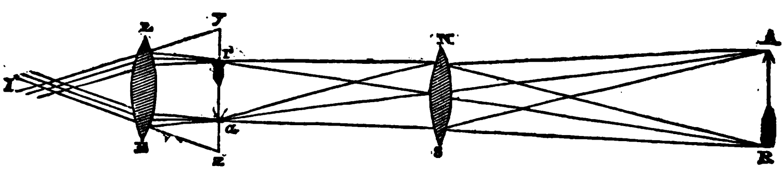


fig. 191.

distance, N S the object-glass, behind which and a little beyond its focus will be the diminutive inverted image of the object viewed at *r a*. L E is the object-glass, and as it magnifies, the image is viewed under the angle I *y z*, and is seen as at the dotted arrow. Thus then objects are seen in an inverted position, which is of no consequence in astronomical observations. It is usual to fix the object-glass at the end of a tube longer than its focal distance, and to place the eye-glass in a small tube, which will slide out of and into the larger tube, for the purpose of adjusting it to objects at different distances.

The magnifying power of this kind of telescope, named refracting, is

found by dividing the focal distance of the object-glass by the focal distance of the eye-glass; thus, if the focal distance of the object-glass be 150 inches, and it admit of an eye-glass whose focal distance is 3 inches, the 150 divided by 3 gives 50 for the number of times the telescope will magnify the diameter of an object.

When two additional lenses are added to the astronomical telescope, it then becomes a terrestrial telescope, or perspective glass, and objects are seen by it in their right position.

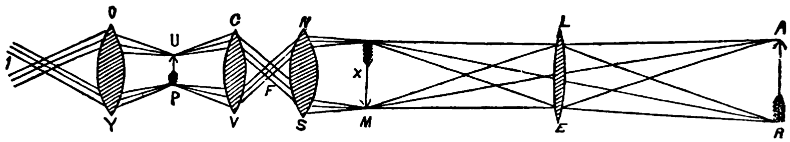


fig. 192.

A R is the object, from which the rays of light pass through the object-lens L E, and form the image M at X, which is the focus of the lens N S, from whence, having crossed at the focus F, they pass on to the next glass C V, and in passing it they are converged to the points in its other focus, where they form an erect image U P; and as this is the focus of the eye-glass O Y, and as the eye when at I is at the same distance on the other side, the image is seen through the eye-glass in this upright position. As the three eye-glasses have all their focal distances equal, the magnifying power is found by dividing the focal distance of the object-glass by the focal distance of any of the eye-glasses.

In the year 1663 a young man of the name of James Gregory published a work pointing out the defects of the refracting telescopes, and proposing the substitution of a metallic speculum for the object-glass, on which to receive the image and reflect it towards a small speculum of the same material. Want of means or mechanical ability caused this idea to remain dormant until 1672, when Sir Isaac Newton, finding that the errors arising from the refrangibility of light were greater than those from reflection, formed two reflecting telescopes on the principle, though not quite the plan of Gregory. These were only six inches long, but equal to a refractor of six feet; the reflecting telescope admitting of an eye-glass of a shorter focal distance than a similar refractor, its magnifying powers are increased.

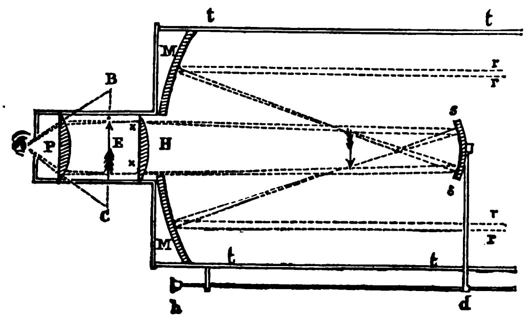


fig. 193.

In the Gregorian telescope M M (fig. 193) are the concave metallic mirrors forming together a speculum; the small arrow represents the inverted image formed by it of the object proceeding from rays *r r r r*. This image is reflected again by another small concave speculum *s s* placed

before the great speculum, and in its axis, and thus it forms the erect image E, which to an eye at P will appear magnified. The small speculum is adjusted by means of a screw and rod *h d*, which is fitted on the outside of the body, *t t t t*. The image might have been viewed and magnified by the convex eye-glass at P alone, but it is generally preferred to receive the converging rays upon a lens H, called the field-glass, which hastens their convergence and forms the image in the focus of the lens P, by which they are magnified and rendered more distinct. This telescope possesses the advantage of being capable of direction in the line of sight towards the object, as well as the objects being seen upright; but from the hole in the middle of the object-speculum the quantity of light is diminished, and the objects less distinctly seen.

In the Newtonian reflecting telescope, previously alluded to, the large concave speculum *c c* (fig. 194) is placed at the end of the tube; the rays proceed from the object *a b* to the speculum *c c*, and are reflected to the mirror *e e*, supported or hung by *f*; and from thence at right angles to the double-convex lens *g*, where they are refracted to the eye at *i*. If the small mirror *e e* was dispensed with, the rays from *n o* would converge to *d*, at which place the eye of the observer would see the image of the object *a b*; but as his head would intercept a portion of the rays, the small speculum *e e* and convex lens *g* are arranged as in the diagram.

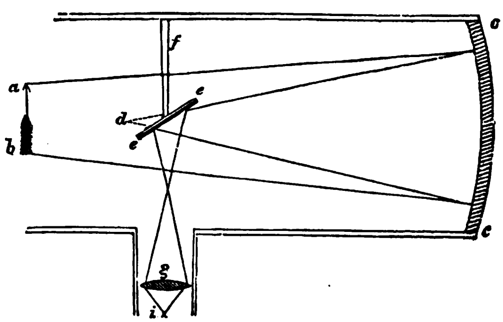


fig. 194.

The gigantic telescope at Slough near Windsor was after several failures completed by Sir William Herschel in 1789, and magnifies 6450 times. With this a satellite of Saturn was instantly discovered, and also a new planet, which received the name of Herschel. The tube of this surprising instrument is 39 feet 4 inches long, its diameter 4 feet 10 inches. The great metal mirror is 49½ inches in diameter, but the polished surface only 48 inches, its thickness 3½ inches, and its weight before being polished 2118 lbs. It magnifies objects nearly 7000 times, and brought 36,500 times as much light into the eye as would have been derived, without such aid, from the object. At the open upper end of the tube which is directed to the heavens the observer sits with his back to the object investigated, which he sees by rays reflected from the great mirror through the eye-glass at the opening on one side of the tube (fig. 195): *s* is the speculum set at such an inclination to the axis of the tube which contained it, that the inverted

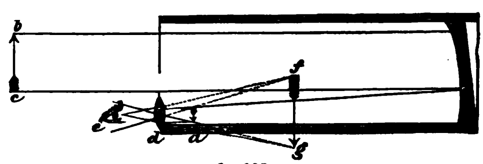


fig. 195.

image *a* which it formed of an object *b c* was projected towards the edge of the tube: *d* is the eye-glass through which *e* would see the enlarged image *f g*.

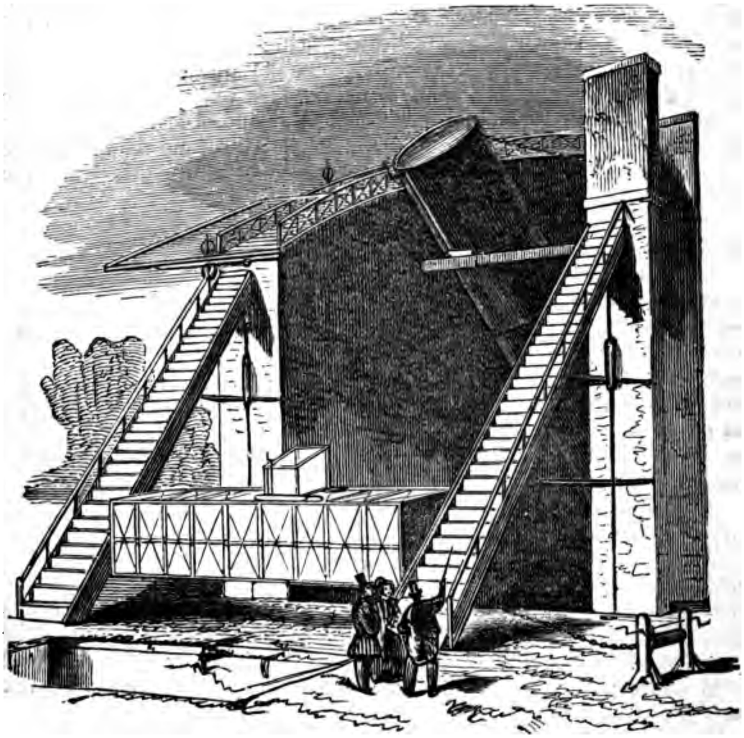


fig. 196.

A triumph in reflecting telescopes has been accomplished by the energy, genius, and wealth of Lord Rosse; the description of which wonderful piece of scientific mechanism we take from the *Illustrated London News*.

"The diameter of the large speculum is 6 feet, its thickness $5\frac{1}{2}$ inches, its weight $3\frac{3}{4}$ tons, and its composition 126 parts of copper to $57\frac{1}{2}$ parts of tin; its focal length is 54 feet: the tube is of deal; its lower part, that in which the speculum is placed, is a cube of 8 feet; the circular part of the tube is at its centre $7\frac{1}{2}$ feet diameter, and at its extremities $6\frac{1}{2}$ feet. The telescope lies between two stone walls, about 71 feet from north to south, about 50 feet high, and about 23 feet asunder. These walls are, as nearly as possible, parallel with the meridian.

"In the interior face of the eastern wall, a very strong iron arc, of about 43 feet radius, is firmly fixed, provided, however, with adjustments, whereby its surface facing the telescope may be set very accurately in the plane of the meridian—a matter of the greatest importance, seeing that by the contact with it of rollers attached to one extremity of a quadran-

gular bar, which slides through a metal box fixed to the under part of the telescope tube, a few feet from the object end of the latter, whilst its other extremity remains free, the position of the telescope in the meridian is secured, or any deviation from it easily determined; for on this bar lines are drawn, the interval between any adjoining two of which corresponds to one minute of time at the equator. The tube and speculum, including the bed on which the latter rests, weigh about 15 tons.

"The telescope rests on an universal joint, placed on masonry about 6 feet below the ground, and is elevated or depressed by a chain and windlass; and although it weighs about 15 tons, the instrument is raised by two men with great facility. Of course, it is counterpoised in every direction.

"The observer, when at work, stands in one of four galleries, the three highest of which are drawn out from the western wall, whilst the fourth, or lowest, has for its base an elevating platform, along the horizontal surface of which a gallery slides from wall to wall by machinery within the observer's reach, but which a child may work.

"When the telescope is about half an hour east of the meridian, the galleries hanging over the gap between the walls present to a spectator below an appearance somewhat dangerous; yet the observer, with common prudence, is as safe as on the ground, and each of the galleries can be drawn from the wall to the telescope's side so readily, that the observer needs no one else to move it for him.

"The telescope lying at its least altitude can be raised to the zenith by the two men at the windlass in six minutes; and so manageable is the enormous mass, that, by giving the right ascension and declination of any celestial object between these points, the object can be brought into the field of the telescope within eight minutes from the first attempt to raise it.

"When the observer has found the object, he must at present follow it by rackwork within his reach. As yet it has no equatorial motion, but it very shortly will; and at no very distant day clockwork will be connected with it, when the observer will, whilst observing, be almost as comfortable as if he were reading at a desk by his fireside.

"Fig. 197 shews a view of the inside of the eastern wall, with all the machinery seen in section. A is the mason-work in the ground; B the universal joint, which allows the tube to turn in all directions; C the speculum in its box; D the tube; E the eye-piece; F the movable pulley; G the fixed one; H the chain from the side of the tube; I the chain from the beam; K the counterpoise; L the lever; M the chain connecting it with the tube; Z the chain which passes from the tube to the windlass over a pulley on a truss-beam, which runs from W to the same situation in the opposite wall—the pulley is not seen; X is a railroad on which the speculum is drawn either to or from its box—part is cut away to shew the counterpoise. The dotted line *a* represents the course of the weight R as the tube rises or falls; it is a segment of a circle, of which the chain I is the radius.

"With a little attention to these several points, the working of the machinery, we think, will be easily comprehended. The weight on the lever L sinks only 15 feet under the horizontal position; it then rests on the ground, and is, of course, no load on the tube, which is, when this happens, 30 degrees above the horizon. Below this point the tube is

sufficiently heavy to descend when the windlass unrolls the chain. Then suppose the tube makes the angle of 30 degrees with the horizon, and that it is required to elevate it, the windlass is turned, and the chain

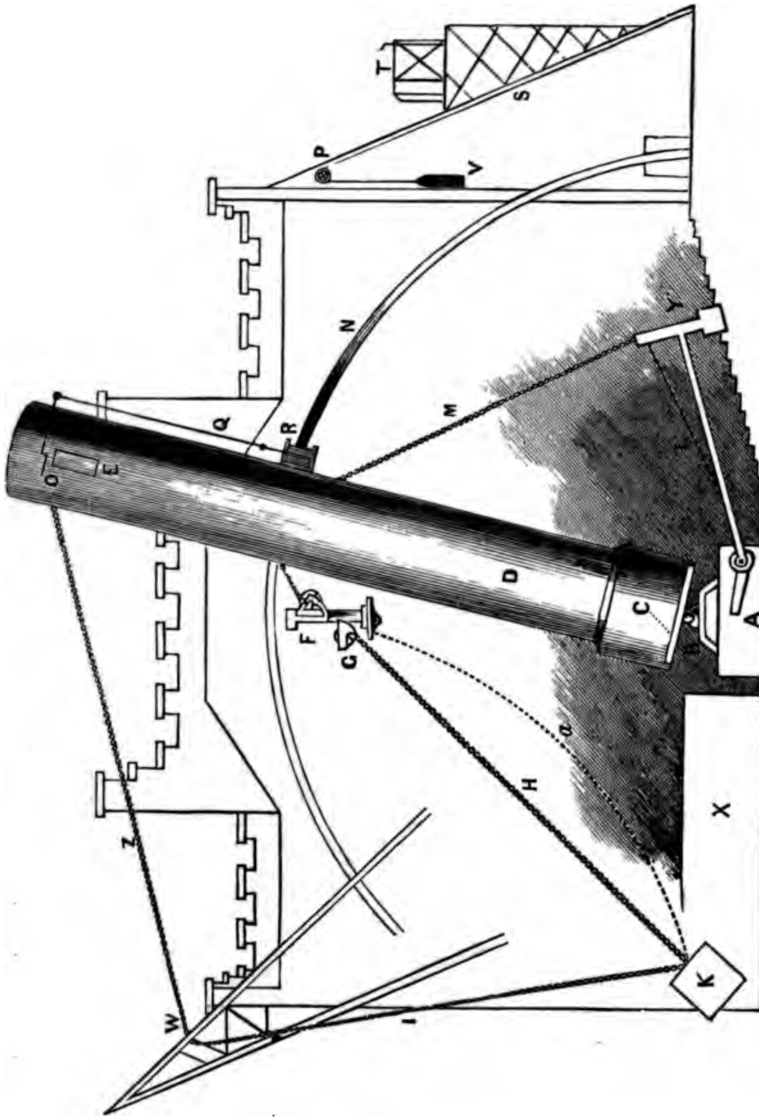


fig. 197. A sectional view of Lord Rosse's telescope.

being shortened, the desired effect is produced; but the labour of this would be immense if the counterpoise K did not assist: this nearly balancing the tube, leaves but little exertion to be made at the windlass. *However, the weight of* the tube, according as it ascends, is gradually

becoming less and less, until it produces no strain at all on the windlass when it is quite upright. This must evidently be the case from the first principles of mechanics; for making the tube a lever, the length of its arm continually decreases as it approaches the perpendicular; therefore, if the counterpoise continued the same weight on the tube towards the end as it was in the commencement of the ascent, it would be too heavy, and would keep it in its perpendicular position. In fact, the counterpoise must become lighter as gradually and as evenly as the tube itself, in order to continue to be just the same support to it all through its movement. The plan adopted to effect this is beautifully simple: a weight hanging freely in a perpendicular direction, exerts its greatest force on the suspending point; if it be moved from the perpendicular, as much power as is required to effect this is taken off from the same point; as will be evident to any person pushing aside a hanging body, he must apply a certain degree of force to keep it out of its perpendicular position; and this might be mathematically proved to amount to exactly the degree of weight that is taken off the point from which the body hangs. Now, it will easily be seen, when the tube is ascending and losing its weight, also lengthening the chain H, that on account of the chain I, whose length is always constant, the counterpoise K is moving from the perpendicular position under G, and therefore losing its power on the tube, and approaching the perpendicular under W, and for this reason transferring all its weight to the fixed chain I; when the tube passes the perpendicular, the chain H is again shortened, and the counterpoise begins once more to draw it back; so that the action of this tends to keep the tube always upright to whatever side it may point, and its power is always equal to the varying weight. Under these circumstances, we see how easily and evenly the windlass can elevate the telescope and turn it to the north; but when it arrives there it must be brought back again; and this is accomplished by the lever L. As we have seen that the action of the tube and counterpoise is so regulated, that in all positions the weights, although always changing, are equal to one another, so must the weight of the lever vary with its position in order to be a perfect balance on the tube; and this it evidently does. We said, that when the tube was perpendicular the weight on the lever is most effective, for it is at the farthest distance it can be from the support; it therefore pulls down the tube when the windlass is unrolled; but we saw that the tube as it descends increases its weight; so that if the lever continued acting with the same power with which it commenced, the weight of both would be constantly increasing; this is prevented by the lever losing its force as it falls; for the weight thereby, of course, approaches the support, and cannot be so active; but the approach to the support by its descent is so regulated to the increasing distance of the end of the tube in *its* descent by the chain M, that in the same degree as the latter gains weight the former loses it; and in this manner there is a constant equilibrium kept up between them. When the tube reaches within 30 degrees of the horizon the lever rests on the ground, and the tube is thence able to descend by its own weight. When the tube points to the north, the lever is elevated above the horizon, and has not, of course, so much power as when it coincided with it; but it is in this case helped by the counterpoise K, which always tends to bring the tube to the perpendicular. This continues to help it until it becomes itself sufficiently able, from its horizontal position, to do all the

work; it then commences opposing it; but it now has the help of the increasing weight of the tube itself; and so all the parts are elegantly blended into one another with the most perfect concord and efficiency.

"The manner in which the tube is moved from wall to wall is accomplished by the ratchet and wheel at R, in the above cut; the wheel is turned by the handle O, and the ratchet is fixed to the circle in the wall. The ladders in front, as shewn in the sketch, enable the observer to follow the tube in its ascent to where the galleries on the side-wall commence; these side-galleries are three in number, and each can be moved from wall to wall by the observer, after the tube, the motion of which he also accompanies by means of the handle O."

When light is bent by a convex lens, there is a slight separation of the prismatic colours, which tinges the extremities of the objects viewed; this causes a serious indistinctness, which Sir Isaac Newton feared would prevent the perfection of the telescope. To remedy this, Euler, the Swiss philosopher, from an examination of the human eye, recommended the adoption of a double object-glass of two lenses, having water between them. This led to experiments by Mr. Dollond, a celebrated English optician, to discover if possible a transparent medium, by which there would be refraction without colour; and as different kinds of glass were found to have different dispersive and refractive powers, it was thought by combining two media all the colours might be refracted equally. For this purpose Dollond composed his lenses of one convex lens of crown glass, and one concave of flint glass. The refracting angles were inversely as the dispersive powers of the respective glasses. The concave lens prevented the dispersion of colour by the convex, while there was sufficient convergence of the rays for the formation of the image, and thus the desideratum was accomplished. Fig. 199 will better explain the arrangement necessary to correct this imperfection.

fig. 198.

In this figure, L L is a convex lens of crown glass, and *l l* a concave one of flint glass. A ray of the sun L falls at F on the convex lens, which

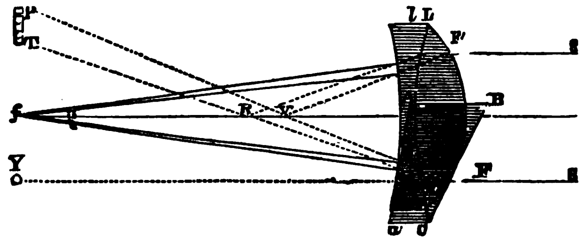


fig. 199.

will refract it exactly in the same manner as the prism A B C, whose faces touch the two surfaces of the lens at the points where the ray enters and quits it. The solar ray S F, thus refracted by the lens L L, or prism A B C, would have formed a spectrum P T on the wall, had there been no other lens, the violet ray F V crossing the axis of the lens at V, and going to the upper end P of the spectrum, and the red ray F R going to the lower end T. But as the flint glass lens *l l* or the prism A *a* C, which receives the rays F V, F R, at the same points, is interposed, these rays will be *united at f, and form* a small circle of white light; the ray S F of the sun

being now refracted without colour from its primitive direction S F Y into the new direction F*f*. In like manner, the corresponding ray S′ F′ will be refracted to *f*, and a white and colourless image of the sun will be there formed by the two lenses.

In this combination of lenses, it is evident that the spherical aberration of the flint lens corrects to a considerable degree that of the crown one, and, by a proper adjustment of the radii of the surfaces, it may be almost wholly removed. Dollond named his telescopes achromatic, from two Greek words meaning without colour.

Dr. August gives the following method of estimating the magnifying power of telescopes, and the extent of their field of vision : the magnifying powers may be estimated pretty nearly by looking at the same object with one eye through the telescope and with the other naked, and comparing the apparent magnitudes of the two images. This measurement may be rendered still more exact if any kind of telescope, except a Galilean, be pointed towards a clear part of the sky, and a leaf of thin paper or transparent horn be held behind the last eye-glass, at the spot where the eye is ordinarily placed ; a bright, strongly defined luminous circle will be visible on the transparent plate, supposing it to be held at the right spot. Measure its diameter as accurately as possible, and then measure the width of the object-glass, using the same scale in each case ; divide its diameter by that of the luminous spot, and the quotient will give the magnifying power of the telescope.

The luminous circle is, in fact, an image of the object-glass itself, whence it may be proved that it is contained in the diameter of the object-glass as many times as are equal to the magnifying power of the telescope. The object-glass may be taken out, and a rim, or annulus, having exactly the same opening as will be equal to the circle of light, put in its place ; the quantity of light will be increased, and the images of objects rendered more distinct by this alteration. Ramsden contrived a little instrument, to which he gave the name of dynamometer, for measuring the powers of telescopes.

The field of a telescope may be estimated by comparing its diameter with the apparent diameter of some object viewed through the telescope. In the choice of an object, one should be selected whose apparent diameter is already known to us ; that of the sun or moon will answer the purpose well; they are both equal, or very nearly so, the apparent difference amounting only to half a degree, or 30 minutes. Or the field may be measured by directing the telescope to some star in or very near to the equator, care being taken that it shall pass over the *middle* of the field, and then count the number of seconds which elapse during its passage : four seconds of time will make an angle of one minute for the field of vision. For a full description of the uses and wonders of the telescope, we beg to refer to Hind's *Astronomy,* forming one of this series of educational books.

THE MICROSCOPE.

The telescope opened out to man's view a gigantic system of worlds in boundless space almost too large to be grasped by his intellect ; while another optical instrument, the microscope, has revealed worlds in miniature so immense in numbers, so perfect in organisation, surrounding man in all space and matter, nay, preying upon and in his body, enjoying their existences and performing all the duties imposed upon them by the laws

of nature, and yet so small as to be hidden from the unaided eye. They exist in such myriads as to cause man merely to write figure after figure as the amount in a single invisible point; from having no means of comparison, man is at a loss to convey to others the miracles of a superior and almighty power.

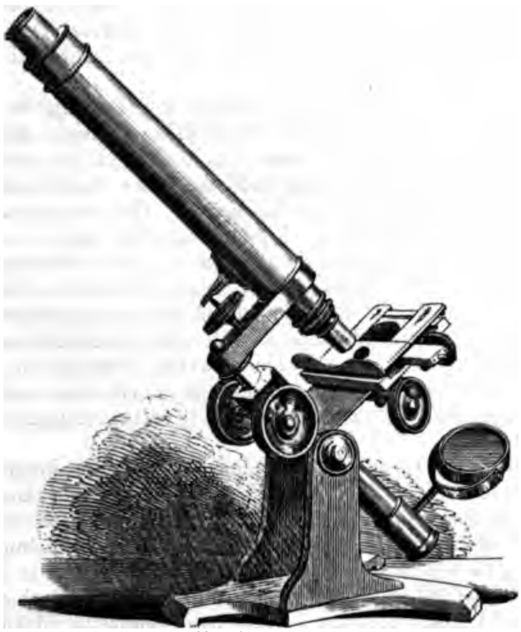


fig. 200. The Compound Microscope.

The word microscope means, to see what is small, and the most powerful instruments resemble in construction an inverted telescope; but as the latter forms an image of a distant object just in proportion so much smaller than itself as the distance of the image from the glass is less, the former having a small object placed near the focus of the object-glass produces a more distinct image, as much larger than itself as the image is more distant, for which purposes there is a proper adaptation of object-glasses, that of the telescope being generally large, that of the microscope very small. Thus, if the focal distance of an object-glass in a microscope be one-eighth of an inch, and the object be so situated that its image is formed at six inches, the image will be of a diameter forty-eight times as great as the object; and when seen through an eye-glass of half-an-inch focus, it will seem magnified twelve times more, or 30,000 times larger than the real size of the object.

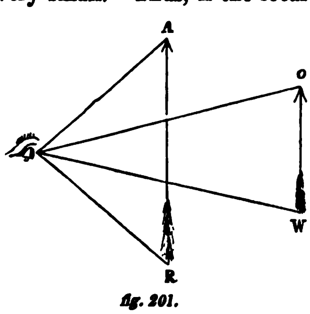


fig. 201.

As we cannot see small objects nearer than about six inches, we make use of glasses to look at them nearer than this

distance, because the apparent size of objects are measured, as we before observed, by the angle under which they are seen by the eye, which of course must be greater or less as the object is nearer or more distant; thus, if A R, fig. 201, and O W be two equal objects, one, O W, at the distance of "distinct vision" from the eye, six inches, and the other, A R, at half that distance, that we may be able to see A R we must place a convex lens between it and the eye, to cause the rays proceeding from the object to pass out of the lens, and thus converge to a focus on the retina of the eye.

fig. 202.

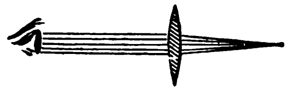


fig. 203.

When an object is too near the eye (fig. 202), the rays are too divergent to admit of distinct vision; hence, by applying a convex lens (fig. 203) the rays are rendered parallel to the eye, the object distinctly visible, and the convex lens becomes a single microscope.

Microscopes are of three kinds, the single, compound, and solar.

The magnifying power of the single microscope is found by dividing the distance a person sees at best, by the focal distance of the lens; thus, if a person sees an object well at 6 inches, and the focal distance of the lens be 1-10th of an inch, it is said to magnify lineally, or in one direction, 60 times, and the surfaces will be magnified 60 times 60, or 3600 times.

A compound achromatic microscope is a beautiful piece of delicate mechanism, possessed of all the appliances of science, and has been brought to a wonderful state of perfection. It consists of two compound lenses, by one of which, the object-glass, an image is formed within the tube of the microscope; and this image is viewed instead of the object, and re-magnified by the eye-glass.

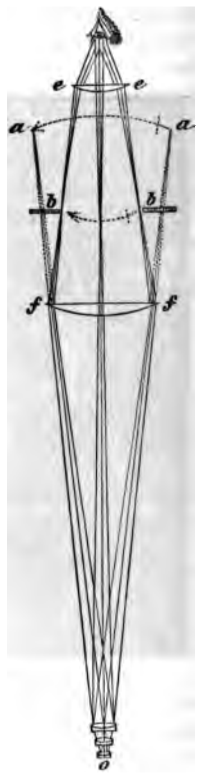


fig. 204.

A section of a modern compound achromatic microscope, as manufactured by our best makers, is represented by fig. 204, where *o* is an object; and above it is seen the triple achromatic object-glass, in connexion with the eye-piece *e e*, *f f* the plano-convex lens, *e e* being the eye-glass, and *f f*, the field-glass, and between them at *b b* a dark spot or diaphragm. The course of the light is shewn by three rays, drawn from the centre, and three from each end of the object *o*; these rays, if not prevented by the lens *f f*, or the diaphragm at *b b*, would form an image at *a a*; but as they meet with the lens *f f* in their passage, they are converged by it and meet at *b b*, where the diaphragm is placed to intercept all the light except that required for the formation of a perfect image; the image at *b b* is further magnified by the lens *e e*, as if it were an original object. The triple achromatic combination constructed on Mr. Lister's improved plan, although capable of transmitting large angular pencils, and corrected as to its own

errors of spherical and chromatic aberration, would, nevertheless, be of little service without an eye-piece of peculiar construction. As this subject has been so admirably treated by Mr. Ross in the *Penny Cyclopædia*, it has been thought most desirable to quote his own words, as follows:—

"If we stopped here," says Mr. Ross, "we should convey a very imperfect idea of the beautiful series of corrections effected by the eye-piece, and which were first pointed out in detail in a paper on the subject, published by Mr. Varley, in the fifty-first volume of the *Transactions of the Society of Arts*. The eye-piece in question was invented by Huyghens for telescopes, with no other view than that of diminishing the spherical aberration by producing the refractions at two glasses instead of one, and of increasing the field of view. It consists of two plano-convex lenses, with their plane sides towards the eye, and placed at a distance apart equal to half the sum at their focal lengths, with a stop or diaphragm placed midway between the lenses. Huyghens was not aware of the value of his eye-piece; it was reserved for Boscovich to point out that he had, by this important arrangement, accidentally corrected a great part of the achromatic aberration. Let fig. 205 represent the Huyghenian eye-piece of a microscope, F F being the field-glass, and E E the eye-glass, and L M N the two extreme rays of each of the three pencils emanating from the centre and ends of the object, of which but for the field-glass, a series of coloured images would be formed from R R to B B; those near R R being red, those near B B blue, and the intermediate ones green, yellow, and so on, corresponding with the colours of the prismatic spectrum. This order of colours is the reverse of that of the common compound microscope, in which the single object-glass projects the red image beyond the blue.

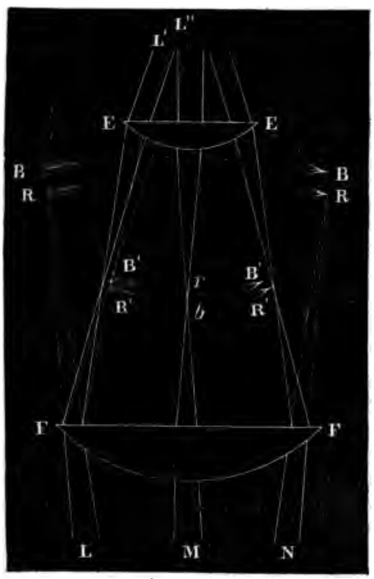


fig. 205.

The effect just described, of projecting the blue image beyond the red, is purposely produced for reasons presently to be given, and is called over-correcting the object-glass as to colour. It is to be observed also, that the images B B and R R are curved in the wrong direction to be distinctly seen by a convex eye-lens, and this is a further defect of the compound microscope of two lenses. But the field-glass, at the same time that it bends the rays and converges them to foci at B′ B′ and R′ R′, also reverses the curvature of the images as there shewn, and gives them the form best adapted for distinct vision by the eye-glass E E. The field-glass has at the same time brought the blue and red images closer together, so that they are adapted to pass uncoloured through the eye-glass. To render this important point more intelligible, let it be supposed that the object-glass *had not* been over-corrected, that it had been perfectly achromatic; the

rays would then have become coloured as soon as they had passed the field-glass: the blue rays, to take the central pencil, for example, would converge at b, and the red rays at r, which is just the reverse of what the eye-lens requires; for as its blue focus is also shorter than its red, it would demand rather that the blue image should be at r, and the red at b. This effect we have shewn to be produced by the over-correction of the object-glass, which protrudes the blue foci BB as much beyond the red foci RR as the sum of the distances between the red and blue foci of the field-lens and eye-lens; so that the separation BR is exactly taken up in passing through those two lenses, and the whole of the colours coincide as to focal distance as soon as the rays have passed the eye-lens. But while they coincide as to distance, they differ in another respect,—the blue images are rendered smaller than the red by the superior refractive power of the field-glass upon the blue rays. In tracing the pencil L, for instance, it will be noticed that, after passing the field-glass, two sets of lines are drawn, one whole and one dotted, the former representing the red, and the latter the blue rays. This is the accidental effect in the Huyghenian eye-piece pointed out by Boscovich. The separation into colours of the field-glass is like the over-correction of the object-glass,—it leads to a subsequent complete correction. For if the differently coloured rays were kept together till they reached the eye-glass, they would then become coloured, and present coloured images to the eye; but fortunately, and most beautifully, the separation effected by the field-glass causes the blue rays to fall so much nearer the centre of the eye-glass, where, owing to the spherical figure, the refractive power is less than at the margin, that that spherical error of the eye-lens constitutes a nearly perfect balance to the chromatic dispersion of the field-lens, and the blue and red rays L″ and L′ emerge sensibly parallel, presenting, in consequence, the perfect definition of a single point to the eye. The same reasoning is true of the intermediate colours and of the other pencils."

Dr. August gives the following method of ascertaining pretty accurately the magnifying power of a compound refracting microscope. An object, of which the size is known, has to be placed before the object-glass; then looking with one eye through the microscope, with the other look at the points of a pair of compasses, held at the distance of distinct vision before it. Having adjusted the compasses to the diameter of the object seen through the microscope, divide this diameter by the known diameter of the object, both being in the same denomination, and the result will be the magnifying power sought.

A solar microscope is for transparent objects, and can only be used with the hydro-oxygen light, or when the sun shines strongly, the rays from which, being received on a plane mirror, are reflected through a lens called a condenser, in a shutter or through a tube, into a darkened room; and nearly in the focus of these condensed rays another lens is placed, so as to obtain a large amount of light, but at the same time avoiding the heat rays, which would otherwise fall upon the object placed within the burning focus. The object-glass is adjusted to bring the object exactly in its focus, thence the rays cross and diverge to a white screen on which the image is seen: the magnifying power depends on the distance of the screen from the window. This microscope is employed that several persons may at the same time see the same object. It has also lately

been used for throwing the magnified images of microscopic objects upon prepared photographic surfaces of a very large size, and with surprising effect. The Hydro-oxygen Microscope is a modification of the solar; a jet of hydrogen and oxygen gas being ignited, is allowed to play on a small cylinder of lime placed in the interior of the instrument.

The luminous effects produced by exposing lime to a jet of the ignited gases is familiar to every one. This brilliant light was first adapted to the illumination of the microscope by Charles Woodward, Esq., F.R.S., who succeeded in exhibiting transparent objects by its aid, and thus rendering this valuable instrument of philosophical research available at all times and for many purposes; the beauty of the *Dissolving Views* may be especially instanced. The instrument, which was designed by Edward Clarke, Esq., of the Royal Panopticon of Science, to whom we are indebted for the descriptive

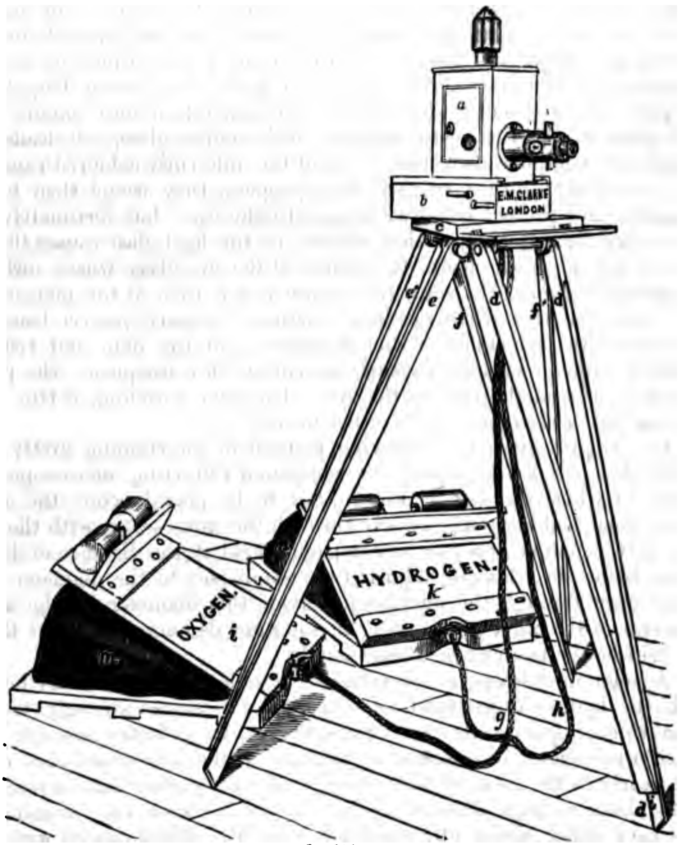


fig. 206.

matter and drawings, is one which may be used with perfect safety; and by an improvement effected in the disposition of the lenses, affords the operator greater magnifying power, of a more achromatic character, greater and more uniform light, and better definition of objects. All this has been obtained,

not by adding to, but chiefly by reducing the number of lenses employed for the condensation of light, and by dispensing with metallic reflectors.

THE STAND, LANTERN, AND CAOUTCHOUC GAS-HOLDERS.

In fig. 206, *a* represents the mahogany lantern and its sheet-iron chimney; *b* the mahogany base, on which the lantern can slide in a dove-tail groove, so as to permit the movement of the lenses to or from the lime-light. This base is hollow and pierced, to admit the ascent of a current of air between the first condensing lens and the lime-light, which keeps the former cool, and carries off the volatilised particles of lime, which, if allowed to settle on the glasses, would impair their transparency. *c* is a triangular frame supporting the base *b*. A shelf is seen in front attached to the frame *c* by a pair of hinges, which permits it when not in use to fold up in front of the base *b*; and when wanted, to hold the objects for exhibition, powers, &c. *d, d′ e, e′, f, f′*, are the three pairs of legs of a tripod support for the whole.

The arrangement for the supply of gases possesses many advantages: the principal one is, that by an elongation of the flexible tubes *g h*, the gas-holders may be placed in a separate apartment, so as completely to obviate any objections to the exhibition of the gas microscope in family circles. The two gases are kept perfectly isolated until brought together at the point of the blowpipe for combustion. They are introduced (by means hereafter described) into separate bags, provided with pressure-boards and weights; the name of each gas being distinctly branded on its proper pressure-board *i, k*, to avoid the possibility of mistake. Each bag is connected with the blowpipe by a separate flexible tube *g, h*; these tubes are attached by union-joints and stop-cocks to the gas-bags *m* and *n*, which are constructed of india-rubber cloth, perfectly air-tight.

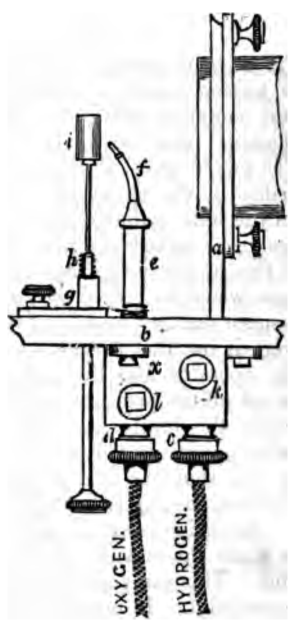


fig. 207.

Fig. 207 affords a skeleton view of the parts connected with the gas blowpipe. *a* is a side view of a portion of the front of the lantern, supporting the tube that holds the condensing lens; *b* is the mahogany base before mentioned, on which the lantern slides, and through which the blowpipe and lime-holder *h*, bearing the lime-cylinder *i*, are firmly inserted. A square piece of brass *x* is fixed on the bottom of the base *b* by three screws. *c, d* are two hollow projecting cylinders with exterior screws cut upon them, the threads of which are concealed in the figure by the union-joints that connect them with the flexible tubes which convey the gases (oxygen and hydrogen) from their respective bags, fig. 206, *i, k*. Their passage through the solid piece of brass *x* in the figure before us,

is regulated by two stop-cocks, the handles of which are not shewn in this figure, but may be seen at *l* and *k*, fig. 207, through which they are allowed to enter the blowpipe *e* and combine within it, in given quantities, so as to produce the most brilliant effect when finally propelled and ignited at the platina nozzle *f*. A spring slit in the outer sliding tube of the blowpipe at *e* permits the nozzle *f* to be elevated or depressed without danger of leakage; and an universal joint at its base allows it to be further directed with ease and efficiency in any lateral direction.

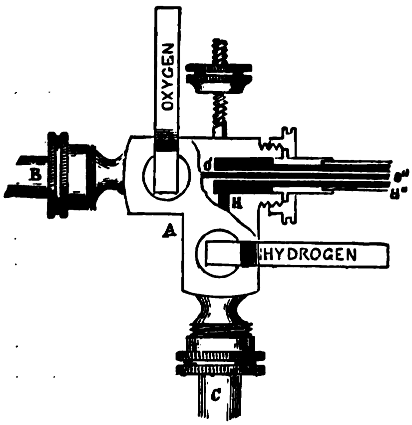


fig. 208.

Fig. 208 exhibits the manner in which the gases enter separately into the blowpipe. A is a piece of brass cast solid, and pierced so as to admit the passage of the two gases. Both cocks are now shewn shut. The oxygen gas enters by the pipe B, and when the stop-cock is opened, continues its passage directly along the central tube from O′, to the extremity O″, to which the little chamber nozzle of platina is attached by a screw. The hydrogen gas is admitted by the pipe C, and when the cock is opened for its passage, finds its further way into the outer chamber H surrounding the oxygen passage O′, and then enters the six small pipes seen only in section; and so continues to the extremity H″, where it is emitted, and combines with the central stream of oxygen gas in the minute chamber provided for that purpose in the interior of the platina nozzle. The mixed gases then pass on in intimate union, and out through the orifice of the blowpipe nozzle, where they are combined and directed on the lime cylinder for the purpose of illumination. As the two gases are never mixed in any greater quantity than is contained in the interior of this nozzle, no greater amount of explosion can at any time take place than would be caused by the trifle contained in the "platina chamber;" a space scarcely worthy of the name (being not larger than a pin's head), were it not that it serves a purpose of safety and of signal, important to the operator and the apparatus. Whenever the cocks are shut so as to cut off the pressure and supply of the gases, the flame naturally retires within the nozzle, and ignites the little explosive mixture which it contains, producing a distinct snapping noise, something like that occasioned by the shutting of a penknife, and indicating the quiet termination of combustion, explosion, and danger of any kind.

Attention must be paid to the position of the blowpipe nozzle so as to attain the most favourable distance and direction for playing upon the lime. This can easily be ascertained and regulated by means of the universal joint. It must be recollected during these trials, that the lime-cylinder is a substance possessed of very slight cohesion; and that it is liable to be rapidly volatilized or carried off by the action of the blowpipe

wherever any one portion of the surface is continuously exposed to the intense heat generated at the point of the flame. To prevent this, you must turn the lime-holder every three or four minutes by the milled head at the bottom of the spindle *h*, fig. 207, so as to expose a new surface to the action of the hydro-oxygen jet. This is a troublesome duty, but it must be carefully executed, otherwise the surface of the lime-cylinder *a* would be worn into a hole similar to that represented at *b* fig. 209, the concavity of which would throw back the inflamed gases against the interior condensing lens *c*, and thereby most probably crack it into a thousand pieces. Magnesia or quartz may be substituted for the lime with advantage.

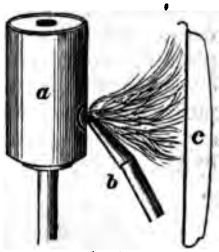


fig. 209.

The tube attached to the front of the box is shewn in fig. 210. *g* is the tube which supports or holds in its prolongation those which carry the objects and magnifying powers. It is firmly screwed into the larger tube *f* by the single-milled rim adjoining, which gives the operator the means of turning the entire of the tubes extending from *g* to *p*, with all the powers and objects that may be contained in them, completely round, either from right to left, or from left to right. The tube *h* is the object-holder. It carries within it a spring tube, which by means of four pins, two of which are shewn at *l*, *m*, can be easily pushed inwards towards *g*, so as to open a space for the introduction of the slider containing the objects. On inserting the slider and removing your hand from these pins, the action of the spiral spring will instantly cause the return of the inner tube, so as to close up the vacant space and hold the slider firmly in its place. The objects are brought into the proper focus by a revolving movement of the large milled head *i*, which turns a pinion that acts on a rack in the interior of *h*, and thereby causes it to advance or retreat within *g*, until the slider is adjusted to the exact distance requisite to throw a perfect image on the disc. The portion of the tube in advance, marked *n*, is the *power-holder*, which receives the three magnifying-glasses (or *powers*, as they are technically termed) used in this microscope. Only one is used at a time. That shewn in its place, marked *p*, is the lowest power of the three, and the most suitable for a learner to commence with. It magnifies about 10,000 times.

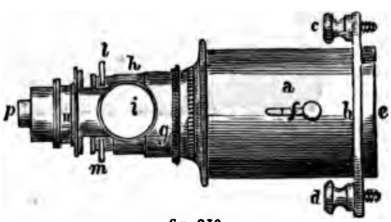


fig. 210.

TO MAKE AND COLLECT THE GASES.

The first step towards the use of the microscope is the preparation of the oxygen and hydrogen gases. This is a very simple operation, and may safely be entrusted to any servant of ordinary intelligence after one practical lesson.

In fig. 211, *a* is a cast-iron retort, into which is screwed, air-tight, a piece of gun-barrel tube *b*, with a screw for a union-joint at the other end.

Pour into this tube as much black oxide of manganese in coarse powder as will fill the body *a*; then place the retort in a good kitchen

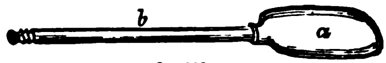


fig. 211.

or parlour fire, in the position shewn in fig. 212. The best fuel for the purpose is coke intermixed with charcoal; but any clear-burning fire in any common fireplace will answer the purpose; the heat may be increased by using a common pair of bellows, or the blower *d*.

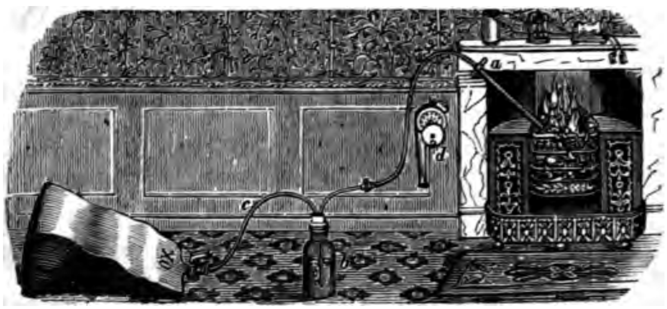


fig. 212.

After waiting for a few minutes to allow the atmospheric air and moisture to escape, connect by means of the union-screw *a* the end of the iron-tube which forms the neck of the retort to the glass bottle *b*, which is arranged for cooling the gas in its passage, which otherwise might injure the india-rubber cloth bag, by the degree of softness the heat would occasion. It is three-fourths filled with water. The wide mouth is closely fitted with a brass cap cemented upon it, through which pass two flexible metallic tubes; one of these (before mentioned) conducts the oxygen gas from the retort, and opens beneath the water within a quarter of an inch of the bottom. From this orifice the gas issues freely in separate bubbles, to be deprived of its heat as it ascends through the water, which will further retain any condensible impurities that may happen to be volatilised in the process.

When the bag is full, shut the stop-cock, and if more gas be required, instantly undo the connexion with the conducting-pipe *c*, and transfer the supply to another bag. When the charge in the retort has given forth all its oxygen, it should be taken from the fire, and, having first undone the union-joint at *a*, and removed the flexible pipe that connected it with the bottle, the residual oxide of manganese should be thrown out, whilst still red-hot, by turning the retort with its mouth downwards, and shaking it briskly in a pair of calliper-tongs. If left to cool, the oxide will cake together and become difficult to extricate.

As possibly some of our readers may not be fully acquainted with the properties of oxygen gas, it may be as well to mention, for the removal of any doubts or fears they may entertain, that there is not the slightest danger attending any part of the above process for its production. The gas is not in the least combustible or explosive, either separately or mixed, whether with common air or with any of the gaseous adulterations which are known to occur either by accident or design. Finally, the

raw material (the black oxide of manganese) is perfectly harmless; and we have heard of no inconvenience attending the operations of pounding, sifting, and handling it. The residual brown oxide obtained when the retort is emptied is also similarly inert.

Fig. 213 exhibits the arrangement for the preparation of hydrogen gas. *a* is a lead or thin glass bottle, with two pipes made of glass firmly fixed through a brass cup which screws into its mouth. This bottle is filled to about one-third with zinc cuttings. The upright pipe *b* ends in a funnel, to allow of one part sulphuric acid and six parts of water being poured into the bottle upon the zinc. The bent one permits the passage of the generated hydrogen gas, and is provided with a union-joint at *c*, to connect it with the glass bottle *d*, containing water for its purification.

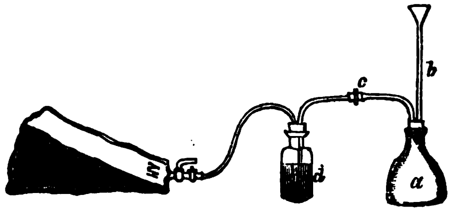


fig. 213.

It is necessary to allow all the common air included in the generator and purifier to escape in the first instance, even though some hydrogen be lost at the same time, previous to receiving the gas in the bag H Y, otherwise an explosive mixture would be formed in it. A little experience will soon enable the experimenter to form a correct opinion whether all the atmospheric air has been expelled, and whether the hydrogen is passing purely through the water in the purifier. When it is generated at a

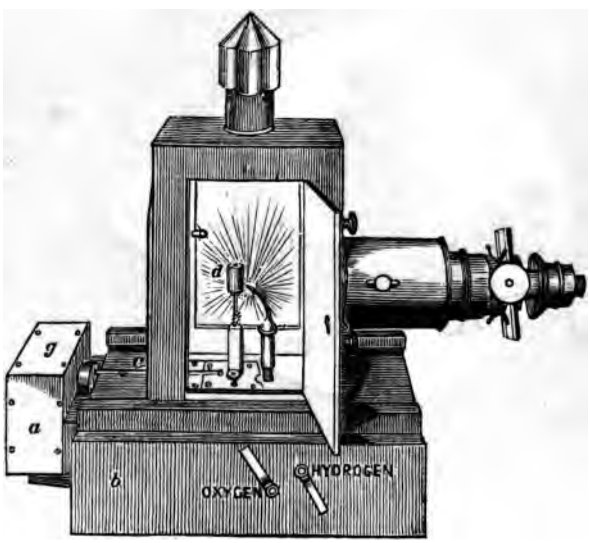


fig. 214.

proper rate, three or four bubbles will be seen to issue smartly from the pipe *c* every second, and then discharged through the water with a very peculiar sound, not loud but distinct, and unlike any other; arising perhaps from their great levity, being 11,000 times lighter than the water

through which they pass, and the consequent rapidity with which they spring to the surface.

Take care not to approach the purifier or the open union-joint *e* with a lighted candle while the mixture of air and gas is passing off, for being together lighter than the atmosphere, it would ascend, and, if it come in contact with the flame, readily explode, and possibly crack the glass bottle; thereby, in all probability, spilling the water and thus deranging and delaying the process, as well as wasting the hydrogen gas in progress of generation, though no greater mischief would be likely to happen. In most cases the preparation of hydrogen gas may be dispensed with, as the ordinary carburetted-hydrogen gas supplied by the gas companies to the house will answer the purpose very well.

Having effectually guarded against leakage by ascertaining the completeness of all the union-joints, the next step is to complete the blowpipe arrangement by putting a lime-cylinder *d* on the lime-holder; fig. 214 shews the arrangement of the interior of the lantern, with *a, g*, a brass box attached, containing a small piece of clock-work motion to keep the lime cylinder revolving. This only need be added when cost is no object.

When you have perfectly dried the lime by turning on the hydro-

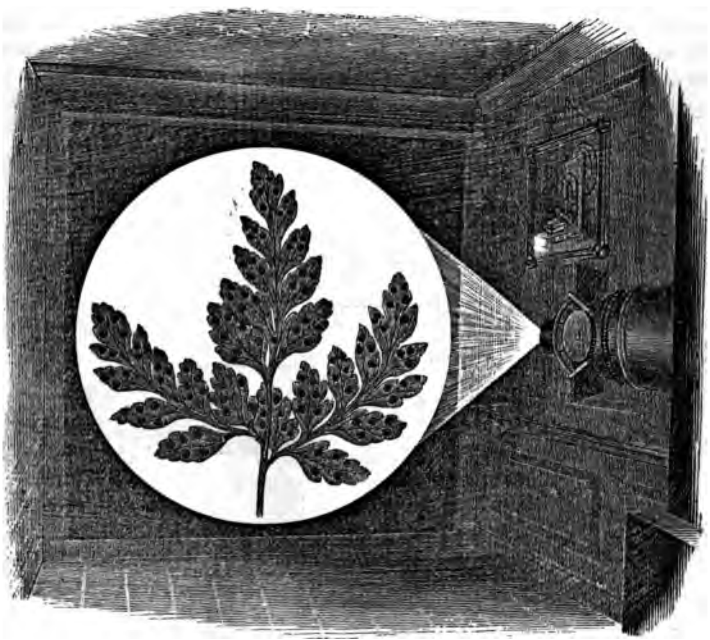


fig. 215.

gen-jet alone, you may introduce the oxygen gas into the centre of the flame by gently opening the stop-cock. Should you do this suddenly, you will extinguish the flame altogether. When the oxygen is skilfully and patiently admitted, the compound flame will produce a brilliant glow on the lime-cylinder altogether different from, and vastly superior to, the

best effect produced by the hydrogen-jet. You may now attain the highest intensity of light by holding the oxygen and hydrogen stop-cocks one in each hand, adjusting nicely the influx of both gases, and watching the effect on the lime-cylinder through a piece of coloured eyeglass in the side of the lantern, if the naked light be too powerful for the eye, until by gradually increasing or diminishing the supply of each, you arrive experimentally at the proper proportions of both. An excess of hydrogen will be indicated by the appearance of a reddish flame surrounding, and of course obscuring, the glow of white light that radiates from the cylinder. Additional oxygen will remove the redness; but an excess of this gas will diminish the white light, and if the proportion be increased, will at last extinguish it altogether.

The first point in the management of the lantern is to obtain a uniform disc of light on the whitewashed wall, or on a white linen or calico screen hung perpendicularly against it for the purpose. When you find that the lime-cylinder *d* is giving out an intense steady light, place the low magnifying power on the end of the tube, shut the door of the lantern, and exclude every other light from the room except what passes through the microscope to the wall. When you turn your eyes towards the disc produced there, you will perhaps be much disappointed at beholding its centre only lit up, and darkness radiating towards the circum-

fig. 216.

ference; or, *vice versâ*, the centre very dull, and a scattered illumination towards the edge of the circle. These defects are, however, easily removed; both are occasioned merely by the want of adjustment of the focal distance between the lime-light and the first condensing lens; and

both may be obviated by sliding the body of the lantern which carries the lens (while the light stands fast) to and fro in the groove at the top of the base-board, until the proper focal position be attained, when the disc of light will be uniform throughout.

This being accomplished, you may proceed to put the apparatus to work—to illuminate and magnify the objects prepared for the purpose. These are generally set between two pieces of glass in a long thin mahogany frame, and usually consist of the wings of flies, moths, and butterflies, the wings and wing-cases of beetles, bugs, locusts, and grasshoppers, the feathers of birds, the cuttings of wood, some of which are extremely beautiful, the scales of fishes, the petals and leaves of plants, the branches of mosses, &c. The family of ferns furnish a numerous and very interesting class of objects. A specimen of which is shewn in fig. 215, and is well seen with a low magnifying power.

A large class of objects may be obtained amongst the temporary inhabitants of the waters, the larvæ of various libellulæ and gnats. The exuviæ or cast-off skins of spiders, caterpillars, and other insects that undergo metamorphoses, also form interesting subjects of examination. The various dissections of the trachea and bronchiæ of caterpillars present very curious and beautiful objects.

Fig. 216 is the perfect fly of a very interesting aquatic insect, the Nepa, or water-scorpion.

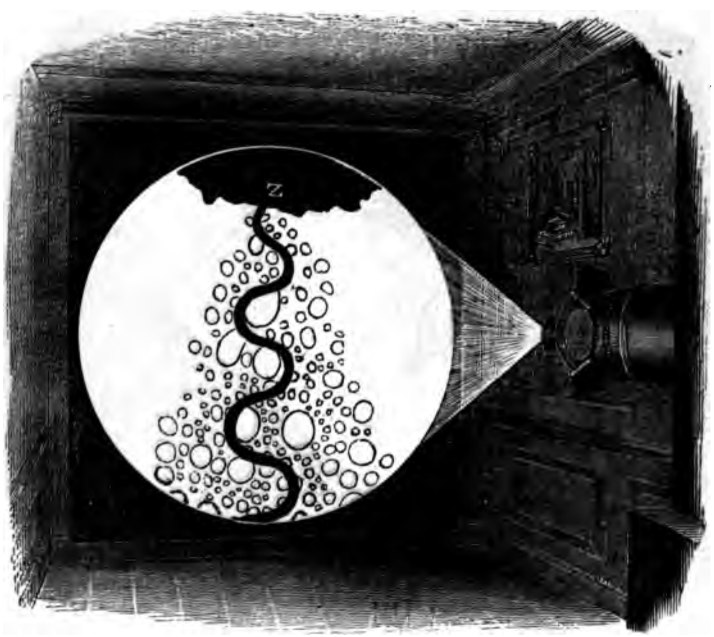


fig. 217.

The decomposition of water by chemical action presents a very curious appearance under the gas microscope, fig. 217. This exhibition is effected by the adaptation of a glass trough to the microscope (to be introduced

horizontally in the manner of a slider), containing dilute sulphuric acid (similar to that employed in the preparation of hydrogen gas), and dropping into it a few pieces of fresh broken zinc. Decomposition of the water instantly commences. Its oxygen gas combines unperceived with the zinc, which then dissolves gradually in the sulphuric acid; while the hydrogen gas set free at the same instant rapidly rises in bubbles through the liquid and escapes at the surface. These bubbles, magnified, present a most extraordinary appearance, forming a series of whitish luminous globules descending in the fluid (for every thing appears reversed in the microscopic exhibitions) from an opaque surface, and swelling enormously as they struggle to the surface under the trebly expansive powers of heat, combination, and lessening pressure.

A beautiful series of objects may be shewn by the crystallisation of various salts from chemical solution; or we may turn to the vast field of animalculæ life presented in a single drop of standing water, for subjects of wonder and admiration. If we take a little sour paste diluted with water, and place a drop of the mixture on a single glass slider, and introduce it in the same way into the microscope, we shall find an object of singular interest presented to our view on the illuminated disc: tens of thousands of living animalculæ, resembling eels, are seen struggling and twining in masses so densely congregated, that it appears as if they alone constituted the paste. Their numbers defy all attempts at calculation while they are free to move; but as the water evaporates under the influence of the transmitted heat, these agitated masses are seen to grow gradually more and more quiescent, until at last they lie motionless, rigid, and dead. Then some estimate may be formed of their numbers, and it will probably be found that the drop contained millions. The vast field of observation and inquiry which such a sight opens to zoologists is too obvious to require commentary. We can well conceive that when any lecturer shall arise, able and willing to present to the public comprehensive views of life and organisation, he will not find a single apparatus more suitable to the development of interesting facts in physiology, or the exhibition of preparations in anatomy, than the gas microscope.

It will be necessary to give some information respecting the discs employed by exhibitors. They are of different sorts; fixed or rolling, opaque or semi-transparent. The best is the fixed opaque, for then no light is lost by passing through; and all that is necessary to form one, is to whiten the side of a room like a ceiling. If the room be papered with a raised flock pattern, it will be necessary, prior to colouring, to rub it down with pumice-stone, so as to reduce the inequalities. The white paint used must be a distemper, not an oil-colour, as there must be no gloss apparent. If a circle be struck, and all outside it blackened, the effect in many situations will be rather ornamental than otherwise. Mechanics' institutions, school-rooms, and scientific lecture-rooms, have generally white-washed walls, and no expense need be incurred in such cases, as nothing can answer better; nor is it necessary to blacken the circumference of a disc. Indeed, where the apartment is small, it is a decided disadvantage; for should the room be fourteen feet long and only eight feet high, a disc circumscribed by a black exterior would only shew an object eight feet long; but should the object be a long narrow one, it would be desirable to shew it from one end of the wall to the other.

The *magic-lantern* somewhat resembles the gas microscope in appear-

ance, and may be made so in arrangement, although a cheaper kind is formed of tin, having a chimney to carry off the smoke from a common oil lamp. At the back is placed a concave reflector C, fig. 218, which reflects the light to the plano-convex lens M. From this it proceeds to a transparent painting on glass S, fixed in a slide, so as to be movable:

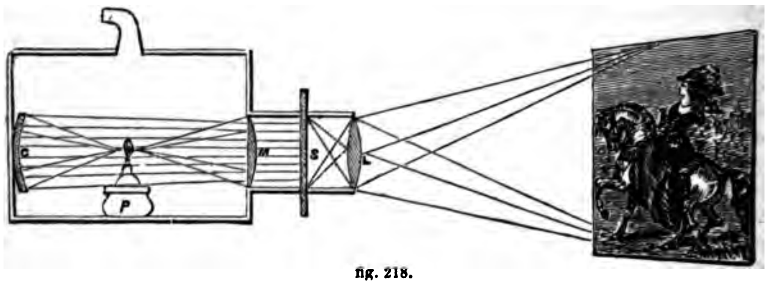


fig. 218.

it is placed in an inverted position. From this slide the light passes to another lens L, which is convex, and fixed in a sliding tube, to enable it to be brought to the requisite distance or focus on a screen in a dark room; a large erect image of the design on the glass is seen painted on the opposite wall.

No public exhibition ever excited such a sensation in Paris and London as that of the Phantasmagoria; by representing horrific figures, that seemed to approach upon the audience from an amazing distance, and then recede again, arise into the sky or descend into the earth,—which being aided by the wild and plaintive notes of the Eolian harp, and other accessories, presented a scene that terrified many visitors, and for some time remained a secret with its discoverer. This optical illusion is nothing more than a magic-lantern, having all the glass opaque, excepting the figure, which is painted in transparent colours. Thus no light can come upon the screen, except what passes through the figure itself. The screen being placed in front of the audience, while the operator is on the opposite side, with the lantern fixed on a table that can be silently moved backward and forward, the figures appear to advance and retire. The size of the images increase when the lantern is carried back, because the rays come in the form of a cone; and as no part of the screen can be seen, the figure appears to be formed in the air, and to move farther off when it becomes smaller, and to approach as it increases in size.

The beautiful optical representations called dissolving views are effected by having two magic-lanterns at an equal distance, both of the same focus; and while the view of one is being withdrawn, the other is merging forth, realising all the imaginary tales of the powers of magic and of fairies.

PHOTOGRAPHY.

"Time was," a writer in the *Illustrated London News* well observes, "when it would have gone hard with any one who shewed pictures of men and scenes that neither pencil, brush, nor hand had touched; and if, in defence, it had been asserted that the sun itself had traced them, the tortures of the rack would have been had in requisition to force the inventor to confess himself a wizard, and to tell his terms of compact with the devil; and even in our own time, though we have passed from the de-

monism, there is a lingering tendency to set down those who go exploring beyond the bounds of knowledge as madmen. Almost any one can find instances; but we are content to mention one which has connexion with our present subject. At the close of a lecture by M. Dumas, the well-known French chemist, a lady came to him in the lecture-room; she had a question of great moment to ask him. 'Did he think it possible that the pictures seen in a camera could be caught and made permanent?'—she was anxious to know what he, a man of science, thought on the subject. Her husband had been seized by the idea that he could fix these pictures; day and night he was haunted by the thought; she feared he might be mad. But if a philosopher like M. Dumas thought there was any probability in the notion, it would give her the belief that her husband might still be in his senses. Dumas assured her that, though he saw no way to fix the pictures, enough was known to prevent him from saying it was impossible, and to make it matter worthy of inquiry. The lady's husband was Daguerre the painter; and some ten years after this conversation with Dumas, he had solved his problem, and taught the world the art which bears his name."

Since the discovery of Photography, the camera obscura has taken a very important position in optical instrument manufacture, and now often costs as much as *50l.* or *100l.* The art of arresting and retaining the reflection of an object on a bright surface, is a great and valuable discovery. So impressed was the noble nation whose sons gave it birth with its importance to mankind, that, with a cosmopolitan spirit, they honoured and rewarded the inventors, and threw its practice open to all mankind.

Mr. Wedgewood, the celebrated porcelain manufacturer, published the first account in 1802 of a method of "Copying Paintings upon Glass, and of making Profiles by the agency of Light upon Nitrate of Silver." He was assisted by Sir Humphrey Davy, but both failed to fix the images; and the process was abandoned, until the successful experiments of Niepce and Daguerre with the prepared surfaces of bitumen, resin, and essential oil of lavender, induced them to try other substances; and eventually they were rewarded by the discovery of the action of light upon the iodide of silver, and the subsequent fixing of the image upon a silver plate. Mr. Fox Talbot also, about the same time, hit upon a method of fixing the images upon paper prepared with a solution of nitrate of silver; this he effected with common salt, and afterwards the same salt as Daguerre employed with his silver plate, viz. hyposulphite of soda, was used by Sir John Herschel.

The year 1839 gave birth to this, and also the electrotype process; two of the most extraordinary discoveries of human ingenuity, which, from the similarity of their results, may be called sister arts, both acting under two of the most mysterious agents of Nature's wonderful works—the one under the influence of light, the other under that of electricity: in the first, light draws; in the latter, electricity models. With the original process it was considered impossible to apply it to production of portraiture; for with iodine alone and the long-foci of lenses employed at first, no picture could be taken in less time than from fifteen to thirty minutes. As the correctness of a portrait produced by this art depends upon perfect immobility during the whole of the sitting, the bare idea of such an application of photography was thought altogether absurd.

It was, however, soon found, that by constructing object-glasses with shorter foci, the operation could be reduced nearly in proportion to the reduction of the length of the focus; so that, by making use of an object-glass of three inches focus instead of twelve, the operation is shortened by four times, and thus portraits are able to be taken.

Within the last two years more wonderful results have been obtained by using a prepared surface of collodion, or gun-cotton and the white of egg; so that at the present time a degree of perfection is obtained, that has elevated the discovery into one of the most elegant and profitable scientific pursuits.

The process of photography, as carried out on metal surfaces, consists in producing a brilliant polished surface, coating this surface with the vapour of iodine and bromine, exposing it to the action of light in the camera obscura, submitting it to the vapour of mercury, washing it with hyposulphite of soda and then with water, and finally fixing it with a solution of chloride of gold.

The polishing of the plate, after cleaning with a weak solution of acid and water, is effected by the aid of charcoal powder and a buff, consisting of a piece of wood covered with cotton velvet represented in fig. 219; coating the surface, by exposing the plate over a glass pan containing iodine for a few minutes, as represented in fig. 220, which is so contrived that it can be slid from the iodine vapour to the next containing bromine. The plate is then placed in a small dark slide, fig. 222, carefully secluded, and exposed in a camera (fig. 221) to the action of light; the camera-box is made of deal or mahogany, about twelve inches or more in length, with a meniscus lens, or a set of achromatic lenses, constructed as pointed out at page 206, and somewhat resembling the eye-piece arrangement of the microscope. A good lens being obtained, it is placed in a tube at one end of a box, with the necessary adjustments, and the instrument is complete. The most simply constructed box is that shewn in fig. 221, where the lens is placed in one box which slides into another, so that by moving the box backward

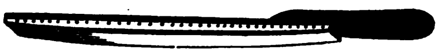


fig. 219.

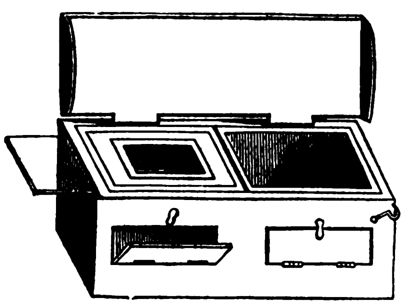


fig. 220.

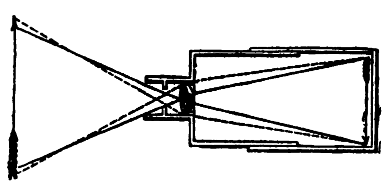


fig. 221.

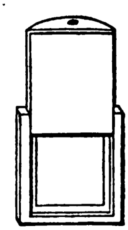


fig. 222.

or forward, we may secure the correct adjustment of the focus, which is determined by the distinctness of the image seen upon a plate of ground glass placed at the extreme end of the outer box. The ground glass at the end of the outer box should be fixed in a frame which falls into a groove, so as to be easily removed or put in its place. Some frames, as fig. 222, should be made which fit exactly into the space occupied by the ground glass; so that, when a frame is put in its place, and the shutter drawn up, the prepared paper or plate coincides in situation with the place occupied by the ground glass previously. Several of these frames may very easily be made to fit into the box, and in each one the sensitive tablet may be placed. The photographer goes into the fields and obtains his pictures, which he carefully screens by closing the shutter of his frame, and so secures them until he is enabled to develop them with convenience.

In combining lenses for the camera, care must be taken not to confound brightness with clearness: they are two things totally different, and the gaining of one does not depend on the other; for it is necessary, generally, to stop a portion of light from falling on the lens, with a diaphragm which has been fully explained in a former chapter. Nevertheless, we think it advisable to give a short explanation more immediately connected with this part of our subject, by attention to which a much sharper picture may be obtained.

Let A B (fig. 223) be a plano-convex lens, and the rays C D E F emanating from the sun, and falling parallel to G K on the flat surface of the glass; the rays D E, near the axis G K, will suffer less refraction than the rays C F, and will form a focus at K, whereas the extreme rays C F will form their focus at H. How, then, is a perfect image to be obtained with this difference of focus? If A H and B H are prolonged to L and M, where the rays meet the plane L M of the focus K, an image of the sun will appear surrounded with a luminous zone, to which the name of *halo* has been given, and which will appear less brilliant the farther it is removed from the centre K. The same reasoning is applicable to all the intermediate rays from C to D and F to E, and their different foci will fall between H and K.

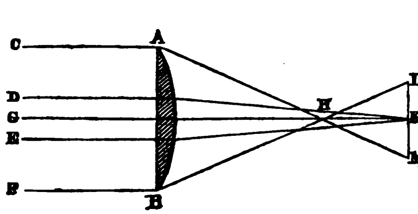


fig. 223.

It is very easy to verify the correctness of these rules; for if the surface of the lens be covered with a diaphragm having a central opening, so as to allow those rays only to pass which are near the axis at G, a clear and sharp image of the sun will be formed at K; and if, instead of the diaphragm, a small disc be used, so as to intercept the central rays, an equally clear image of the sun will be formed at H. These two experiments go also to prove what has before been stated; for, in both cases, the image is rendered sharper, but less luminous. The term longitudinal aberration is given to the distance H K, and that of lateral aberration to the width L M.

Chromatic Aberration.—To understand what is meant by chromatic aberration, it is necessary to bear in mind, what has been already pointed out, that light is decomposible, or, in other words, is the result of a combination or mixture of a certain number of colours, which are considered

as the elements of white light, because they have not yet been decomposed. All the colours which form a ray of white light are not equally refracted by lenses, and consequently cannot meet at the same focus and form a white ray; and not only does this fact explain the colouring of the image, but also the want of sharpness which it presents. The following example will perhaps render the foregoing more easy to be understood.

If L L (fig. 224) be a double-convex lens, and R L, R L, parallel rays of white light, composed of the many-coloured rays, each having a different index of refraction, they cannot be refracted to one and the same point—the red rays being the least refrangible, to V; the distance V *r* constitutes

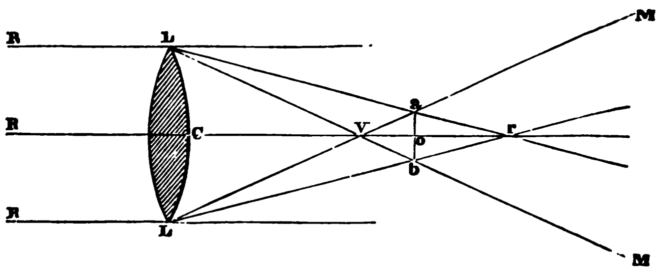


fig. 224.

the chromatic aberration, and the circle, of which the diameter is *a b*, the place or point of mean refraction, and is called the circle of least aberration. If the rays of the sun are refracted by means of a lens, and the image received on a screen placed between C and *o*, so as to cut the cone L *a b* L, a luminous circle will be formed on the paper, only surrounded by a red border, because it is produced by a section of the cone L *a b* L, of which the external rays L *a*, L *b* are red; if the screen be moved to the other side of *o*, the luminous circle will be bordered with violet, because it will be a section of the cone M *a* M *b*, of which the exterior rays are violet. To avoid the influence of spherical aberration, and to render the phenomena of colouration more evident, let an opaque disc be placed over the central portion of the lens, so as to allow those rays only to pass which are at the edge of the glass: a violet image of the sun will be seen at V; red at *r;* and, finally, images of all the colours of the spectrum in the intermediate space; consequently the general image will not only be diffused, but clothed with prismatic colours.

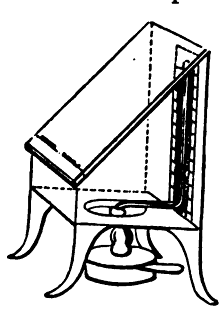


fig. 225.

To correct these and many other imperfections, Mr. Ross has taken much pains to select a particular make of crown and flint glass, and has succeeded in correcting the chemical and visual foci, so that most of the glasses now used consist of two lenses only, one made of flint and the other of crown glass, combined as shewn by fig. 198 and 199, page 252. An exposure of a few seconds or minutes will suffice to impress the image; the plate is then submitted to the vapour of mercury, heated to about 150 or 200 degrees in a box represented in fig. 225, there to remain for several minutes

until the picture is developed, which may be seen by examining it from time to time through the piece of yellow glass let into the side of the box; it must then be removed, and plunged into a bath of hyposulphite of soda (fig. 226), when the iodine will be seen to leave the surface rapidly; afterwards let it be well washed in clean water to free it from the hyposulphite of soda, when it may be placed on a stand (fig. 227), and fixed by pouring a small quantity of the solution of chloride of gold upon the surface, which must be heated by placing a spirit-lamp under the plate until small bubbles thickly arise; and, lastly, the fluid must be thrown away, and the plate quickly dried with the spirit-lamp. The glass and paper processes are conducted in a similar manner to the former, with this difference, that we have now to deal with fluids in place of vapours: the prepared solution of collodion is poured over the surface of a clean piece of glass; it is then immersed in a solution of nitrate of silver; conveyed to the camera, there exposed for a few seconds to the action of light; brought back to the darkened room, the invisible image is developed by pouring over the prepared surface a weak solution of pyrogallic acid; this, after a few minutes, is thrown off, and replaced by a solution of hyposulphite of soda, and finally well rinsed with clean water and stood by to dry. The prepared paper is now chiefly used for the printing of *positives* from glass *negatives*.

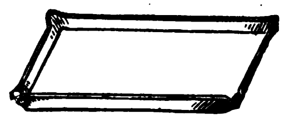


fig. 226.

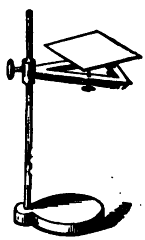


fig. 227.

We find in the daguerreotype process that those parts of iodised silver plate upon which the light has acted with most power, receive, in the exposure to the vapours of mercury, the largest quantity of that vapour over their surfaces, and the gradations of light are marked very beautifully by the thickness of these mercurial films.

It is to be observed that the mercurial vapour does not enter into combination with the surface of the plate, unless it has previously been exposed to the influence of light. A plate exposed to the mercury before and after it had been coated with iodine, was not affected in its after operation in the camera by this premature exposure; so that it is absolutely necessary that the mysterious influence of light should be exerted upon the plate before any degree of affinity exists between it and the vapour of mercury with which it is brought in contact.

The picture may be developed by using the solution of pyrogallic acid as directed for the glass process, also by submitting it to the action of the yellow rays of light, by covering the plate with a piece of yellow glass, without any exposure to the action of the mercury; the effect being so analogous, it would be difficult to decide which had been produced by the mercury and which by yellow light. It is, indeed, most marvellous, that yellow rays should produce upon the plate those white microscopic dots which were assigned only to the combination of mercury; Dr. Moser's theory respecting the formation of the image by the mercurial vapour being, that this vapour developes latent yellow light, and that it is only as continuating yellow rays that the mercury produces the picture.

Mr. Fox Talbot has lately announced the discovery of a process by

which he obtains pictures upon steel plates by the solar rays; and then etches them sufficiently deep for their employment as ordinary steel engravings for printing from. The process is as follows: A solution of isinglass has some bichromate of potash dissolved in it; this is spread over the steel plate and dried by the application of heat. Any object is then placed on the prepared plate, and being pressed close by a glass, it is exposed to sunshine. The yellow surface is rapidly turned brown over all the parts exposed; those covered remaining yellow. If the steel plate be now placed in water, all the unchanged parts are dissolved off, leaving the metal nearly bare. By pouring over the plate some bichloride of platinum, a very fine etching is rapidly made. With proper care very beautiful copies of nature—leaves, flowers, &c.—may thus be obtained.

THE CAMERA LUCIDA.

The Camera Lucida was invented by Dr. Wollaston in 1807, and consists of a four-sided prism of glass set in a brass frame or case. It is screwed on to a table, being supported about six or eight inches from the

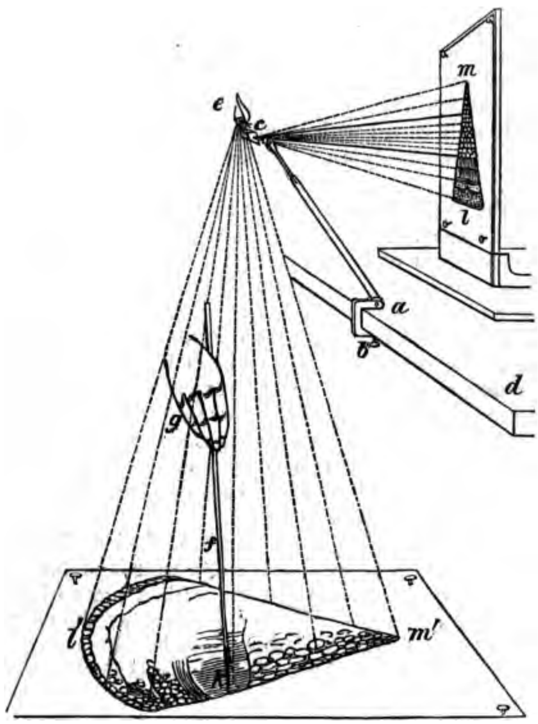


fig. 228. The Camera Lucida.

surface by a sliding tube to suit the sight or position of the object. The rays from the object passing through the glass, are reflected from the lower and back surface of the prism to the eye; and in the same direc-

tion as the last ray, the table or paper placed to receive it is visible, and the image therefore faintly delineated; and as the point of the pencil is also visible, the image may be traced on the paper. A piece of brass having a small hole is fixed on the top, and used as a sight-hole to keep the eye to one point.

Besides the valuable assistance rendered to the draughtsman by this instrument, its application to drawing objects from the microscope, or increasing the size of an object already drawn, for the purpose of shewing an enlarged view or diagram for the lecture-room, may be effected in the following manner. Place the tracing *m l*, fig. 228, made from the microscope by the camera as an object for another camera *c*; this being fastened to the table *d* by the screw *a b*, and the object *m l* set up in front of it, an accurate outline on a larger scale *m' l'* can be made on the floor or table placed four feet below the upright picture, this being the utmost limit of space between *c* and *k* to allow of the pencil being used with advantage. The pencil *k*, with a long handle *f*, being held by the hand *g*, the artist standing either in front or on one side of the camera, and applying his eye as at *e*, may proceed to make an accurate drawing of the object.

To the microscope it is a valuable addition, and is employed to effect drawings of the wonders revealed, without having to move the eye and trust to the fidelity of the memory and accuracy of the pencil.

THE KALEIDOSCOPE.

When Sir David Brewster announced the simple and beautiful little instrument named the *Kaleidoscope*, it excited the attention of every one having the slightest taste, and was as much the subject of conversation, interest, and amusement in family circles as the *Stereoscope* has become since. The kaleidoscope delighted from the variety, beauty, and arrangement of coloured artistic designs; presenting innumerable changes, that with the slightest movement "come like shadows and so depart," the industrial decorator derived from it many valuable hints, and it was an endless amusement to youth. It consisted of a tin tube about ten inches long and from two to three inches wide, blackened inside, and three pieces of looking-glass, or glass painted black on one surface; these were placed in the tube at an angle of 60 degrees. One end of the tube was covered with a cap having a small hole to look through; the other end had a piece of common window-glass, held in its place by a hoop of wire before and behind it; another cap had at the farther end a piece of ground glass, and when fitted on there was a space of about a quarter of an inch between the common glass of the tube and the ground glass of the cap; in this space were placed coloured beads, pieces of glass, or other coloured transparent objects. This end being held to the light, and the eye at the opposite hole, the pieces of coloured glass between the angles of the reflectors were reflected five times, and a beautiful variegated star having six sides or angles met the delighted sight of the observer.

THE POLARISCOPE.

The polarisation of light is a beautiful and valuable branch of science; only being developed by scientific men, it is difficult to place the subject before the reader in a familiar and popular style; yet we should consider our work incomplete without a passing explanation of one of the very

deepest investigations of the secrets of nature yet accomplished, and fraught with most important results.

Brewster says, "if we transmit a beam of the sun's light through a circular aperture into a dark room, and if we reflect it from any crystallised or uncrystallised body, or transmit it through a thin plate of either of them, it will be reflected and transmitted in the very same manner, and with the same intensity, whether the surface of the body is held above or below the beam, or on the right side or on the left, or on any other side of it, provided that in all these cases it falls upon the surface in the same manner,—or what amounts to the same thing, the beam of solar light has the same properties on all its sides; and this is true of light emitted from candles or any luminous bodies, and all such light is called common light." If light be made to fall upon a piece of glass placed at the angle of incidence of $56\frac{1}{2}$ degrees, it then becomes separated into two rays, the one part transmitted and the other reflected. If the glass be made to revolve round in a circle on its axis, the reflected ray, passing off in equal angles with the original ray, will at some positions be transmitted, in others reflected, again transmitted, and so on, which proves that a ray of light possesses different sides, two having the property of transmission and two of reflection; more especially is the case established when, the intensity being the same, there is a marked difference in the brightness of the transmitted and reflected ray. Philosophers thinking, therefore, that light had poles as a magnet, termed a ray thus conditioned polarised. When a prism is used in different positions the two rays will vary in extent, sometimes be doubly refracted, and, in fact, present such variation as corroborates the truth of light having sides. In an instrument contrived to demonstrate the polarisation of light, when turned 90 degrees from the starting point, it undergoes a total change from reflection to transmission, and regularly changes from one to the other at each 90 degrees or quadrature of the circle.

It is found that in all bodies where there seems to be a regularity of structure, as salts, crystallized minerals, all animal and vegetable bodies, on light passing through them it is divided into two distinct pencils. If we take a piece of Iceland spar of the shape termed rhombohedron, and look at a black line or a dot on a sheet of paper, there will appear to be two lines or dots; and on turning the spar round, these objects will seem to turn round also, and twice in the revolution they will fall upon each other, which occurs when the two positions of the spar are exactly opposite, that is, when turned one-half from the position where it is first observed.

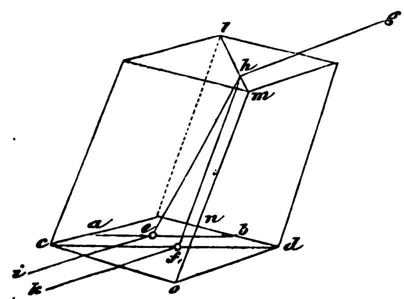


fig. 229.

In the accompanying diagram, fig. 229, the line appears double as $a b$ and $c d$, or the dot as e and f. Or allow a ray of light $g h$ to fall thus on the crystal, it will in its passage through be separated into two rays, $h f$ $h e$; and on coming to the opposite surface of the crystal, they will pass out at $e f$ in the direction of $i k$, parallel to $g h$. The plane $l m n o$ is designated

the principal section of the crystal, and the line drawn from the solid angle l to the angle o is where the axis of the crystal is contained; it is also the optic axis of the mineral. Now when a ray of light passes along this axis it is undivided, and there is only one image; but in all other directions there are two.

If two crystals of Iceland spar be used, the only difference will be, that the objects seem farther apart from the increased thickness. But if two crystals be placed with their principal sections at right angles to each other, the ordinary ray refracted in the first will be the extraordinary in the second, and so on *vice versâ*: at the intermediate position of the two crystals there is a subdivision of each ray, and therefore four images are seen; when the crystals are at an angle of 45° to each other, then the images are all seen of equal intensity.

If we take a piece of that crystallized mineral called tourmaline, of a brown colour, cut in a direction parallel to the axis of the prism, we see a candle through it as if it were a piece of smoked glass, and no change in the candle takes place; but if we place another piece between it and the candle, and turn round slowly the first piece, the candle will appear to be shut off from view at every quarter; turn then gradually, and it will come again into sight, and again disappear. This arises from the axes of the pieces of tourmaline being different, and preventing the passage of the rays of light, only freely admitting them when the axes of both plates are parallel to each other. This Professor Whewell expresses as "opposite properties in opposite directions, so exactly equal as to be capable of accurately neutralising one another."

For the measurement of the angle of polarisation there are various instruments, called *Polariscopes*. Baumgartner's is a plane mirror blackened on the back and inclined at an angle of 57° to the horizon, which receives the light reflected on it by a looking-glass placed at an angle of 33°, the rays from which it polarises and throws up vertically. The rays pass through the circular opening up the tube, which is blackened inside, and by means of a screw attached to the pillar is raised or lowered at pleasure. Over the upper end a ring passes movable about an axis, bearing a frame containing either a blackened glass mirror, or ten or twelve glass plates laid smoothly one on the other. The frame may be placed at a different angle with the axis of the tube. A crystal of double refraction may be substituted for the frame, and may be turned about at the upper opening of the tube. The substances through which it is desired to conduct the polarised ray are laid on a piece of looking-glass set in a ring, and thus can be turned about the axis of the polarised ray.

The angles at which substances polarise light by reflection are: diamond, 68° 1′; sulphur, 63° 45′; Iceland spar, 58° 51′; rock crystal, 56° 58′; glass, 56° 45′; water, 53° 11′.

Professor Daniell, in his *Introduction to Chemical Philosophy*, writes: "If, instead of viewing the reflected ray through a tourmaline, we place another plate of glass so that the reflected ray may fall upon it at the same angle as upon the first, this second plate may be made to turn round its axis without varying the angle which it makes with the ray which falls upon it. When the two planes of reflection coincide with each other, the ray of light, or luminous object, will be reflected from the second glass in the same manner as from the first; but if we turn the second glass round

a quadrant of a circle, so as to make the planes of reflection perpendicular to one another, the whole of the ray will pass through the second glass, and none of it will be reflected. Let us turn the second glass round another quadrant, so as to make the planes of reflection again coincide, and the ray will be again wholly reflected. When the glass has been turned round three quadrants, the light will be again extinguished.

"As both the pencils of light into which a ray is divided by passing through a rhombohedron of Iceland spar are polarised, but in opposite directions, on viewing the reflection of a lamp from glass, at the proper polarising angle, through such a crystal, the two images will alternately appear and disappear as it is turned upon its axis.

"It may perhaps assist our comprehension of the connection of these phenomena to illustrate them by a rough analogy: a ray of common light as it is emitted from a self-luminous body we may conceive to revolve upon an axis coincident with its own direction, as a cylindrical rod may be made to turn; or, which comes to the same thing, the reflecting or refracting surface may be made actually to revolve around the ray as an axis, preserving the same relative position to it in all respects, and no change in the phenomena will be perceived.

"But if, instead of employing such a ray of ordinary light, we subject to the same examination a ray which has been submitted to the action of certain material bodies, and has become polarised in the way which we have just examined, we find this perfect uniformity of result no longer to hold good. It is no longer indifferent in what plane, with respect to the ray itself, the reflecting or refracting surface is presented to it. It seems to have acquired sides, a right and left; a front and back; and to be no longer like the cylindrical stick, but like a four-sided one. If we imagine a surface to be made up of detached fibres all lying in one direction, or of scales or of laminæ arranged parallel to one another, we should find no difficulty in thrusting the cylindrical stick through such an arrangement in any direction, but a flat ruler would only penetrate it in two directions.

"The two rays of light, polarised in opposite planes, after emerging

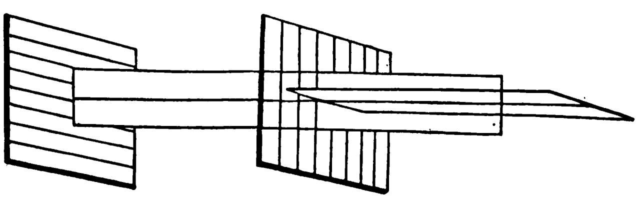


fig. 230.

from a rhombohedron of Iceland spar, may be represented by two such rulers presented to the bars of a grating, in opposite directions, as in fig. 230; while the thin edge of one passed freely between them, they would present an impassable barrier to the other, which would be presented to them crosswise. Supposing the grating to revolve upon its axis, on the completion of the first quadrant, the first would be arrested, and the second would pass; and so they would alternately pass and be stopped at each quadrant of the turn."

If with a plate of tourmaline we examine a polarised ray of white light as it passes through a crystallised substance having a single axis, there are seen rings of various prismatic colours, that change as the position of the tourmaline is altered. On the axis of the tourmaline being brought into the plane of polarisation, then a rich black cross is seen crossing the coloured rings; gradually as the tourmaline is turned, the black cross fades away; and when in the opposite direction, the white one supplies its place, and the second image is complementary to the previous one.

One of the most beautiful phenomena is that of causing a ray of polarised light to traverse a thin plate of mica or sulphate of lime, and then analyse with a plate of tourmaline in that particular position in which without the plate it would wholly disappear, the ray will appear coloured with the tints of the spectrum in vivid intensity, and these may be varied by giving different degrees of inclination to the plate. One of the most perfect specimens of this phenomenon that we have seen was a copy of a gorgeously plumed bird of the parrot tribe, made by Mr. Holmes. On looking at the plate there appeared only a kind of outline stuck upon it; but on placing it so as to receive the polarised ray, the brilliant red, purple, and yellow tints start forth as intense as in nature, and every feather was appropriately tinted. This was effected by carefully cutting away parts, so that they were of different thicknesses, and according as that was regulated so were certain colours affected by the polarised ray.

Many crystals have two axes of double refraction, and coloured rings are formed about both; when nitre is turned upon its axis, the changes of the crosses and coloured rings are most beautiful, seen as in fig. 231. When the line connecting the two axes of the crystal is inclined 45° to the plane of primitive polarisation, the cross seen as first described on revolving the nitre opens and gradually assumes the form of two hyperbolic curves, fig. 232. But if the tourmaline be revolved, the black crossed lines will be replaced by white spaces, and the red rings by green ones, the yellow by indigo, and so on.

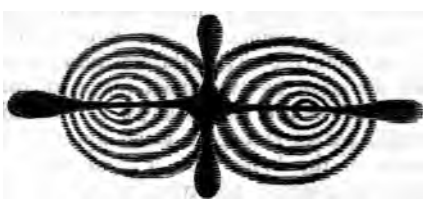


fig. 231. Nitre.

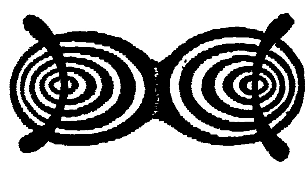


fig. 232. Nitre.

The internal crystalline structure of a transparent medium effects the appearances seen on passing through it a polarised ray. Glass when heated and suddenly cooled, from the outside being first hardened, and the inside struggling as it were vainly to mould the outside to its shape on losing the expansion given it by heat, presents a very curious appearance; this again is varied from the shape being round or square.

The first fig. 233 represents a square piece of unannealed glass; when a polarised beam is transmitted through it, there are seen at its four angles small circular figures separated by a large black cross. When the glass is

rectangle the circular figures appear at the corners, and parallel to the greater sides, instead of the cross, there appear coloured bands.

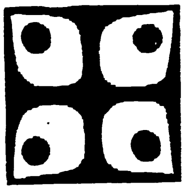


fig. 233.

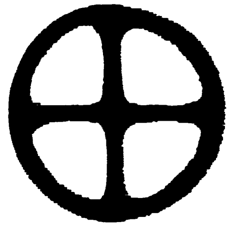


fig. 234.

When the shape is round (fig. 234), there are coloured rings and a large cross intersecting them; and as the shape is altered from square to round, or from round to square, so do the appearances change to those described. When the glass is perfectly annealed, that is, cooled very slowly, this appearance is totally lost.

Circular polarisation has discovered that the rays of each colour are polarised in different planes, and detected differences in the composition of substances that the utmost art of the analytical chemist could not discover, for by this light, it is not the mere structure but the nature of the particles that is elucidated.

The polariscope used by the sugar-manufacturer to discover the quantity of saccharine matter in the juice of the beet-root; by the brewer, to learn the amount of sugar in the wort; and by the medical professor, the extent of sugar in the secretions of the diabetic patient, from which knowledge he learns the effect of his treatment in this fearful malady,—is that contrived by Professor Powell, and is thus described by him:—"The apparatus (fig. 235) is fixed vertically upon any convenient support. The light from a flame or from the sky is thrown into the required direction by two small plane mirrors, S F, inclined at the proper angle to the axis. It thence passes through a small aperture up the axis of the brass tube, T T, in which is inclosed a common test-tube, from 6 to 12 inches in length, filled with the liquid under examination.

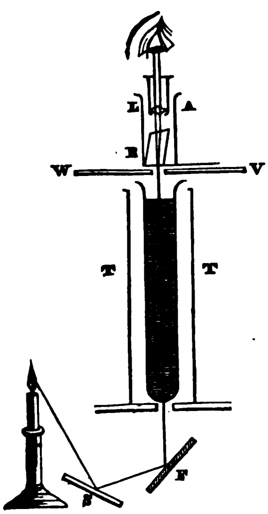


fig. 235.

The analysing part A consists of a graduated rim, W, for measuring the rotation of the index V, attached to the tube containing a rhomb of Iceland spar R, at least one inch or three-fourths thick, in its natural state; having a small hole at the bottom of the tube, through which the light is admitted. In the upper part another tube slides, carrying a lens, L, which magnifies the separation of the images, and gives two sufficiently large well-defined circular images in which all the changes of tint can be distinctly observed.

The wood supports are omitted in the figure, and means should be provided for measuring, as accurately as possible, the length of liquid traversed by the ray in the tube.

Mr. Woodward, before referred to, delivered some popular lectures on the polarisation of light, and afterwards published, at the request of Messrs. Smith & Beck, Opticians, instructions for using a polariscope and microscope combined, as invented by himself. To this publication we are indebted for the following account:

"This instrument is so arranged that it may be illuminated by a candle or argand lamp placed on the table, as in the case of an ordinary microscope; or with the addition of suitable condensers, it may be attached to the lantern of the hydro-oxygen apparatus, and used either as a gas polariscope or microscope for illustrations in the lecture-room.

fig. 236.

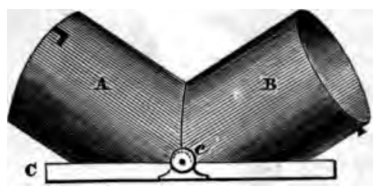


fig. 237.

Fig. 236. A cap fitting on at A, formed by a ring enclosing a piece of ground glass, to disperse the light of the candle or lamp used as an illuminator.

Fig. 237. A B represent the body of the polariscope, formed of two tubes three inches diameter, each inclined at the polarising angle for glass, viz. 56° 45′; C the polarising plates, consisting of eight pieces of thin white window-glass, the lowest being blackened, to absorb the transmitted rays of light. These are attached to the polariscope by screws *c*, and removed at pleasure.

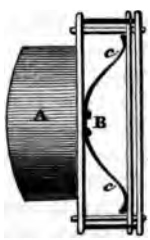


fig. 238.

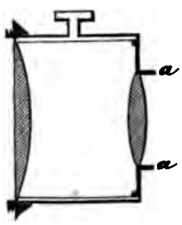


fig. 239.

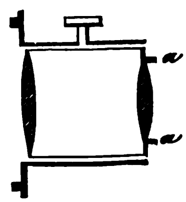


fig. 240.

Fig. 238. A, a tube fitting on at B, fig. 237, and fixed by a bayonet-catch; B, the stage attached to and revolving around the tube A, the objects being kept in position by the springs *c c*.

Fig. 239. The lowest power, to be screwed into the stage B, fig. 238, is composed of two lenses, the first being a plano-convex lens of 2⅞ inches diameter and 3½ inches focus, and the second, slightly crossed, of 1¾ inch diameter and 2½ inches focus. By a crossed lens is understood a double-convex lens, the two sides of which are segments of circles of different diameters.

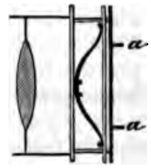


fig. 241.

Fig. 240. A higher power, composed of two crossed lenses, the first having a diameter of 1¾ inch and focus of 2½ inches, and the second a diameter of 1½ inch and focus of 2 inches.

The tourmaline, or other analysing plate, turns freely in a short tube *a a*, fig. 241, projecting from the eye-

lens of the power, and the focus is adjusted by a rack and pinion, or by sliding one tube in the other.

A box 9 inches high, and about 11 inches long, by 7 wide, will contain the whole, and may be conveniently fitted as a stage to raise the polariscope to a convenient height for illuminating and viewing objects on the table. Fig. 242 represents the apparatus properly connected and adjusted for use.

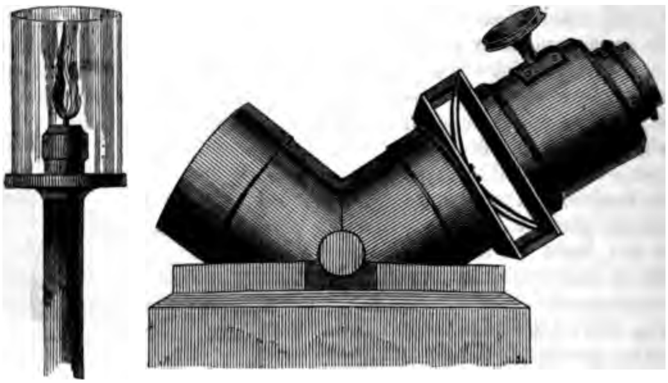


fig. 242.

The instrument arranged with the lowest power affords an extensive field of view, and is thus well adapted for exhibiting the various effects produced by the different forms and thicknesses of selenite and unannealed glass, and for illustrating the interesting phenomena of polarised light generally. It is also calculated for viewing such crystals of salts as have been allowed spontaneously to crystallise on glass; but the arrangement must be altered for observing the phenomena connected with the crystals of calc spar, nitre, quartz, &c. In the first case, the lens or power is used to bring the image of the object to a focus; in the other, it is merely required to cause a great divergence of the rays passing through the crystals; hence, the slide containing them must either be placed immediately between the eye-piece and analyser by means of a small stage attached to the tube *a a* of the power, or the stage and power must be removed, and there must be inserted instead, a double-convex lens of two inches focus, with a stage and analyser so arranged that the crystals may be placed just within the focus of the lens, and immediately under the analyser. In either case, a much larger field of view, and consequently a more beautiful display of coloured rays, will be developed than is obtained by the achromatic microscope. A single plate of blackened glass may be occasionally laid on the bundle of plates (with the intervention of a piece of chamois leather to prevent injury), and substituted with advantage as a polariser in cases where perfect polarisation is more important than intensity of light.

By removing the analyser and the polarising plates, and substituting for the former a cap or stop, with an aperture of $\frac{1}{8}$ inch diameter, and for the latter a silvered reflector, or in other words a looking-glass, the polariscope is immediately converted into a microscope of low power, which will

include within its field all the parts of a large object, such as a butterfly with its wings expanded, the breathing apparatus of a dytiscus, a fern-branch, dissected leaf, &c.; and thus exhibit at one view their relative proportions and connexions."

As direct light cannot be polarised, and reflected light can, Arago shewed that some of the double stars were double suns, and others planets reflecting light, by polarising the light from those bodies.

The polarisation of light forms a wide and beautiful field of inquiry; the phenomena ever presented by it are deeply interesting, as it aids in the analysis of animal, vegetable, and mineral structures, leading to a knowledge of which even the prediction is most startling. "If you can torture and twist a ray of light and prove it to have sides, the discovery may be a curious fact, but of what good is it to society?" Perhaps at first the discoverer might have been nonplused to find an answer; but we now know that, by looking through a piece of selenite at the northern sky, the solar time may be correctly ascertained. Place in the hands of a seaman a polarising prism, and there need no longer be the purgatory of the mast-head, as from the deck the shoals and rocks at the bottom of the ocean may be seen. He whose livelihood depends on entrapping the denizens of the sea may detect their whereabouts by observing the difference in the condition of the reflecting surfaces of the water. A glass may be known fitting to hold hot water, or that would break under such conditions, by means of polarised light, as the annealed and unannealed present different aspects when so viewed. The unannealed piece of glass shewn in a former page would easily break at every point were a set of the coloured rings are seen. The farmer may ascertain at what period his crop is richest in saccharine matter; the brewer and distiller know when their preparations are of the greatest excellence, and thus economise their time and labour, while they benefit by the superiority of their produce. By it, too, we know, from the colours exhibited in transparent or mineral substances, whether the sun's light comes from a solid mass or gaseous envelope, and whether the comets shine by their own or a borrowed light. Still, almost more wonderful are its powers of revelation in the department of comparative anatomy, as we can at once decide by a crystal or particle of bone, what the microscope alone cannot so accurately distinguish, whether it belongs to the fowl, flesh, or fish tribe; whether the substance belonged to a biped or quadruped, hoofed or clawed; to the mineral or vegetable kingdoms. What the ultimate results of this splendid discovery in science may be, it is impossible even to conjecture.

ELECTRICITY.

Five hundred and fifty years before the birth of Christ, Thales, one of the seven wise men of Greece, founder of the Ionic sect, which distinguished itself for its deep and abstruse philosophical speculations, discovered that *amber*, on being excited by friction, possesses the peculiar principle of attracting certain light bodies towards it, which he imagined

to be a kind of animation peculiar to the substance. Theophrastus, or "the divine speaker," three hundred years before the Christian era observed the same property to exist in a crystal supposed to be the tourmaline; and Pliny, in the first century of Christianity, refers to the existence of this extraordinary attractive power in some bodies. In the year 1600, Gilbert, an English physician, published a catalogue of substances known to have the property of attracting light bodies, which was the first attempt to generalise any facts.

Boyle is generally supposed to have been one of the first persons who saw the electrical light by rubbing a diamond in the dark. Otto Guericke, Dr. Wall, and Sir Isaac Newton, added somewhat to our knowledge on the subject. Mr. Grey, in 1728, made a variety of experiments that were corroborated by M. du Fay in Paris. In 1747 Franklin made several discoveries, and in 1752 ventured to draw lightning from the heavens and demonstrate that it was electricity. The "Transactions of the Royal Society" for the year 1770 prove the industry with which Cavendish pursued the science, and the important results he achieved. To the discoveries of Galvani, followed by those of Volta at the close of the last century, we owe the commencement of the science termed Electro-chemistry: Davy's assiduous labours in analysis established it as one of the most useful branches of physical science. The experiments of Wheatstone have developed many wonders; and with the history of this science and electro-magnetism, discovered by Oersted, Faraday has imperishably linked his name to all posterity.

The term Electricity is derived from the Greek word *electron*, signifying amber; in Latin *electrum*.

It is remarkable, that although the discovery of the existence of electricity is of very remote date, yet that hardly any attempts were made to inquire into its principles, and raise it to the dignity of a science, until the middle of the last century. From that period it has formed one of the most pleasing subjects of philosophical investigation, and its progress, consequently, has been most rapid; it has laid bare many truths in the secrets of nature, and now enters most intimately into the social affairs of nations.

Electricity appears to pervade all bodies to a greater or less degree, and when undisturbed produces no apparent effect; but when any body or part of a body becomes possessed of more or less than its natural quantity, it is said to be electrified, and is capable of exhibiting certain appearances. This would not be the case did all bodies receive and transmit it with equal facility.

It is a distinguishing property of electricity, that it both attracts and repels, and communicates those qualities to different bodies; but if two bodies equally electrified, but in opposite states, come into contact, they neutralise each other.

Friction applied to bodies possessing the same peculiarities as amber is called *electrical excitation;* and bodies that are capable of being excited so as to produce electrical effects are named *electrics*.

If we rub a piece of sealing-wax or glass rod on the sleeve of a cloth coat, or with a piece of dry flannel or soft white silk, the wax or glass will attract towards them, and probably lift up, any light matter, as a feather, piece of tissue-paper, gold-leaf, straw, or cork.

A piece of writing-paper warmed, then laid on a table and rubbed with Indian rubber, will be attracted to the table, and when raised from it will cause a slight noise, and sometimes in the dark sparks may be seen.

When a silk stocking is worn over a woollen one, on taking off the silk one a slight snapping noise will be heard.

The fur of a cat rubbed contrariwise in the dark will send forth sparks if it be warm and dry.

Many persons are annoyed, upon attempting to clean their spectacles with a silk handkerchief, at finding they cannot get rid of the dust; in fact, they become more covered, by the electricity produced: this is not the case with wash-leather.

If the windows of a flat shallow glass case be rubbed with a silk duster, the light dust inside will fly up against the glass and back again, and keep dancing in this manner while the rubbing is continued. Thus, then, is shewn in the first place the attraction, and in the second the repulsion, which causes the dust to be driven back. It was this simple occurrence that called Sir Isaac Newton's attention to the subject.

If two small balls turned out of elder pith and hung by a silken thread be brought within a short distance of an excited glass tube, they will be attracted towards it and remain against it; but when the tube is gently moved away from the little balls, they fly off from each other and keep apart for some time,—in fact, until their electricity is dissipated in the air. When still under the influence of the electricity, if the tube be brought again near them, instead of being attracted as before, they are farther repelled. Thus, it appears at first the tube attracted the balls and imparted a portion of its electricity; but when applied a second time, they had sufficient of that kind of electricity, and moved away or were repelled. We use the words "that kind," because if a roll of excited sealing-wax, sulphur, or shell-lac be presented to the balls, they would be attracted; and this same singularity would occur if the last electrics had been used first and the first last.

Thus we learn there are two different kinds of electricity, possessed of opposite properties: that produced by excited glass, to which the name of *vitreous* or *positive* electricity has been given; and that produced by excited sealing-wax, to which the name of *resinous* or *negative* electricity has been applied.

The positive and negative states of electricity attract each other, and when they meet electrical equilibrium ensues. When sufficiently near for their attractive powers to come into action, they violently throw aside any non-conducting power that may intervene. Thus in the heavens, when they come within what is termed the striking distance, the air is suddenly rent in twain, thunder is heard, lightning produced, and an equilibrium of the electrical state of the atmosphere ensues.

If, when a pith-ball is electrified either with excited glass or sealing-wax, we touch it with a rod of glass, its property of being subsequently attracted or repelled by the excited glass or wax will suffer no change; but if we touch it with a rod of metal, it will lose the electricity which it had received, and will be attracted either by the excited glass or wax, as it was when they were first applied to it. Hence the rod of glass and the rod of metal possess different properties, the former being incapable, and

the latter capable, of carrying off the electricity of the pith-ball. The metal is therefore said to be a *conductor*, and the glass a *non-conductor* of electricity.

A non-conductor does not suffer electricity to pass from one part of it to another. For instance, a piece of glass may be excited only in one part, without the other being at all under the influence; and if the whole surface of a tube be excited, it can be felt by sparks in various parts; and if an unexcited piece of glass be placed against an excited piece of glass, the electricity is not conducted away. The case is different with conductors; for if a rod of iron be suspended by a silken thread and charged, as soon as it comes near a body that will receive its overplus of electricity, the whole will pass out in a single spark instantaneously. The same is the case with the human body; but to receive a charge of electricity the person has to be what is teemed *insulated;* that is, by means of non-conductors cut off from all electrical communication with any substance, that would conduct the electricity rapidly to the earth. For this purpose a stool with glass legs is found the most convenient contrivance. The best electrical bodies, or non-conductors, are, gutta-percha, shell-lac, sulphur, amber, resinous substances, jet, glass, and vitreous substances, precious stones (the most transparent the best), minerals, silk, dry external substances, as wool, hair, feathers; paper, parchment, leather, porcelain, loaf-sugar, dry gases, the air, marble, oils and dry metallic oxides, chalk, lime, phosphorus, steam of great elasticity, ice below 0° Fahr.

The principal electrical conductors, or non-electrics, are, silver, copper, lead, gold, brass, zinc, tin, platina, iron, and other metallic substances; well-burned charcoal, plumbago, concentrated and diluted acids, saline solutions, metallic ores, the fluids of an animal body, water, especially salt-water, and other fluids, except oils; ice above 13° Fahr., snow, living vegetable and animal matter, earthy substances, flame, smoke, steam of low pressure, hot fluid resin, and hot glass.

Thus it would seem that the substances in nature from which electricity can be readily excited are non-conductors, and other bodies that are rapid conductors of electric action are non-electric. There are, however, no bodies that entirely prevent or perfectly conduct electric action, the whole being merely a question of degree of capacity.

Persons who devote themselves to an investigation of the science of electricity, in communicating their knowledge, always state whether the kind of electricity on which they are discoursing be positive or negative. This, therefore, must in some manner be ascertained; and the mode is this: they electrify a substance with a known electricity, vitreous or resinous, or what is the same thing, positive or negative, and then, as the body they electrify with the electricity with which they are engaged attracts or repels the other body possessed of the known electricity, it can be decided what the applied electricity is. Suppose some electricity be drawn from the clouds and a pith-ball be charged with it, and another pith-ball be vitreously electrified, then by bringing the cloud-electrified pith-ball to the other, if they are repelled the cloud-collected electricity will be positive, but if they are attracted to each other then the atmospheric electricity will be negative.

No explanation can be given of the cause of the different species of electricity arising from various substances; all that is known is the fact,

and that the body rubbed and the body rubbing become possessed, the one of positive, the other of negative electricity.

If we support two small rods of metal on glass, and place them end to end at a short distance apart, and then charge one of them, electricity will be communicated to the other tube. This is called *electrical induction.* Thus if a tube be electrified, and a suspended pith-ball be placed in contact until it has partaken of its electricity, the ball will be repelled; but if the ball be not electrified, it will be attracted. Move the ball along the tube towards the other one, and the action will gradually become weaker. When tube 1 is withdrawn the powers of tube 2 cease, shewing it was entirely dependent for its electrical influence on tube 1. Faraday discovered that by placing different electrics between the tubes, one kind aided considerably more than the other the passage of the electricity; and calculating these powers, he gave them the term of *specific inductive capacity.*

We have thus glanced at some of the phenomena of electrical action that may be created by means of friction on a glass-tube; but as that method excited only a small quantity of electricity, the electrical machine was invented, whereby a large amount of electricity may be placed at command with little trouble and cost. The machines, although differing in construction, are the same in principle. We proceed to describe that in most common use, fig. 243.

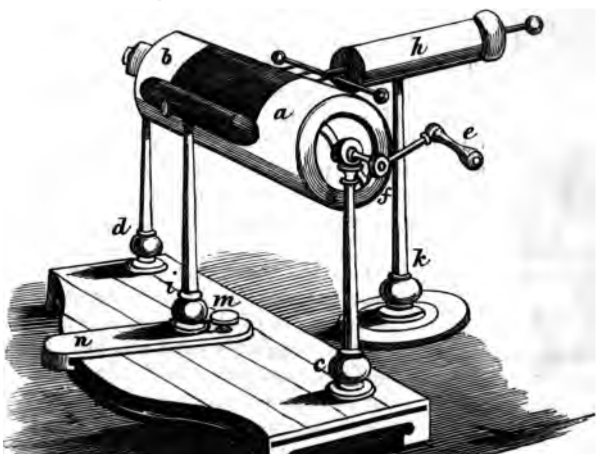


fig. 243. Electrical Machine.

a b is a hollow cylinder of glass, from 4 to 20 inches in diameter, and from 6 to 18 inches in length, having pivots projecting that revolve in round pieces of wood or metal cemented on upright glass pillars *c*, *d*, which, as well as supporting, insulate the cylinder: it is made to turn by means of a winch *e*; *g* is a cylinder of wood covered with tinfoil, supported on a glass pillar *i*, which by means of a groove and screw *m*, at the bottom, can be eased from or pressed against the cylinder of glass. Fastened to the wooden cylinder, and resting with a perfect but gentle pressure against the glass cylinder, is a cushion or rubber stuffed with horse-hair and covered with chamois leather. This cushion is rubbed over with an amal-

gam of 1 part of tin, 2 of zinc, and 4 of mercury. They are separately melted and then mixed. When cold the amalgam is a semi-fluid mass, and can be spread on the cushion. To the cushion is sewed a flap of oiled silk, which lies loosely over the top of the cylinder. On the opposite side is another conductor and points, where the positive or vitreous electricity is collected as it escapes from underneath the silk flap. Both the cylindrical conductors are insulated by being placed on pillars of glass. The apartment in which experiments are made must be dry, and should be warm; and the glass parts, acting as insulators, ought to be coated with a solution of shell-lac in rectified spirits, and when used should be perfectly free from dust.

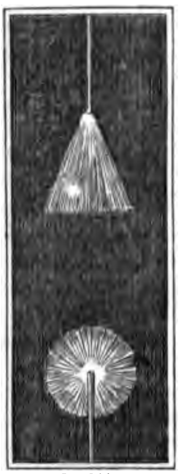


fig. 244.

A chain is attached to the rubber and allowed to rest on the ground, whence the electricity is drawn from the earth. If this chain be withdrawn and attached to the other, which is named the prime conductor *h*, then the positive or vitreous electricity is carried off, and negative electricity is obtained from the other conductor *g*.

When the machine is turned in a dark apartment, the appearance is most beautiful. The conductors being removed, brilliant sparks and streams of vivid light pass from the termination of the flap around the under part of the cylinder to the rubber; a pointed rod of iron held at some distance from the cylinder, in a line with the end of the silk flap, will cause a bright light to be seen as if coming out of the iron point. If points be presented to both conductors at one time, there may be observed at the point presented to the prime conductor *h* a star of light, and at the point presented to the negative conductor the appearance will be like a bright brush or pencil of light, as seen in fig. 244.


fig. 245.

If a person standing near to the conductor place his hand upon it when the machine is being worked, there will be no signs of electricity, because it flows silently through his hand and body to the earth; but if he stand on a stool having glass legs, then, the passage of the electricity being stopped by non-conductors, sparks may be drawn from him the same as if he were the conductor.

If a hole be made in the knob at the outward end of the prime-conductor, and a tuft of feathers be placed in it, then, the machine being worked, the feathers will stand erect and endeavour to avoid each other; as each is electrified by the same electricity, they repel one another.

The phenomena of attraction and repulsion are well shewn by the little apparatus known as the electric-bells (fig. 245). They are suspended by the hook from the end prime-conductor *h*; the two outer bells are suspended by brass chains, while the central one with the two clappers on either side hang from silken strings; the middle bell being connected

with the earth by a thin brass chain. On turning the cylinder the two outside bells become positively electrified, and by induction the central one becomes negative, a luminous discharge taking place between them if the electricity be in too high a state of tension. But if the cylinder be slowly revolved, the little brass clappers will become alternately attracted and repelled by the outermost and inner bells, producing a constant ringing as long as the machine is worked.

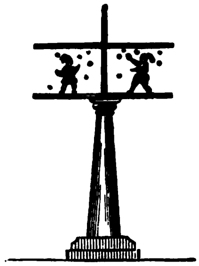


fig. 246.

Let a metallic plate be suspended from the conductor, and underneath it, at a distance of three or four inches, let another plate (fig. 246) be placed; then if some pieces of paper in the shape of the human figure, and a number of small pith-balls be laid upon the lower one, and the machine worked, the little figures and balls will jump to the upper plate, then be repelled, and go on dancing up and down as if actuated with life, labouring among the balls.

There are many other pleasing and elegant experiments to be performed with the aid of the electrical machine, a few of which we shall describe: for many more equally instructive we must refer the reader to the treatise especially devoted to this interesting subject—*Bakewell's Electricity*.

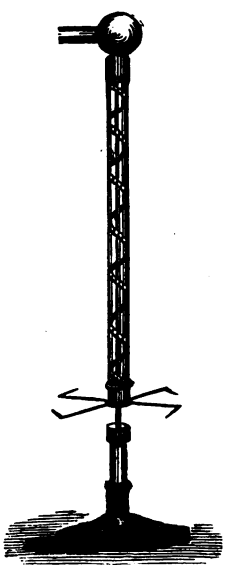


fig. 247.

Barker's spotted tube is a very pretty instrument. It is made of a glass tube, well rounded at one end and open at the other, about ten inches long and three quarters of an inch diameter; a smooth piece of tinfoil is fixed at the upper closed end, and spangles of tinfoil are placed in a spiral form around the tube from end to end (fig. 247). A cap of brass is cemented on the outside of the lower end of the tube, and a strip of foil placed round it. From this ring four wires project outwards, having their points bent at right angles. The tube is then set on an upright wire which passes upwards into the tube to its top, and this wire is then set on an insulated stand, and brought near the prime conductor, when it revolves round and presents a most vivid appearance.

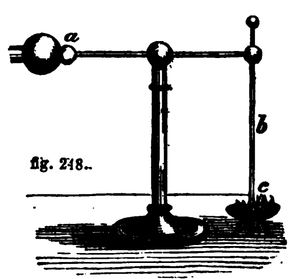


fig. 248.

Place *a* (fig. 248) so as to receive sparks from the prime conductor; pour cold spirits of wine into *c* just sufficient to cover the bottom of the vessel, and set it under the wire *b*; turn the machine, and the spirits will be set on fire.

Take a cake of resin or shell-lac, and after exciting it write with the knob of a jar charged with positive electricity a word on the cake, then waft on it an equal mixture of some finely-powdered sulphur and red lead; the sulphur will fly on to and attach itself to the writing, while the lead separating

itself will entirely cover the other parts of the resinous cake. The effect of this experiment is both beautiful and interesting.

The electrical planetarium, represented in fig. 249, is connected with the prime conductor by means of a chain; and when the machine is set in motion, the reaction of the air against the points *a* and *b* on the wires of the apparatus, causes it to move: the large ball representing the sun, the earth revolving round the sun, and the moon round the earth and sun. This experiment serves to illustrate the force of the current of air which accompanies the discharge of electricity.

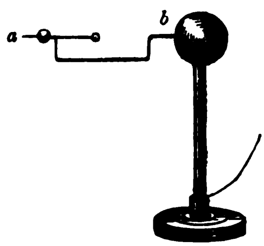


fig. 249.


fig. 250.

If a small pail, with a spout near the bottom, fig. 250, in which there is a hole just large enough to let the water out by drops, be filled with water and fastened to the prime conductor, on turning the machine the water will fly from it in a stream, and in the absence of light seem to be a stream of fire. A wet sponge will act similarly, which is accounted for, says Mr. Noad, by the mutual repulsive property of similarly electrified particles.

Attraction and repulsion are also amusingly seen in the electrical swing: the insulated brass ball *a* is connected with the prime conductor, while the opposite ball *b* communicates with the earth; the little figure on the silken cord is drawn towards *a*, where it receives a charge which it discharges at *b*, and thus he becomes animated, and seems to enjoy his pastime and exercise.

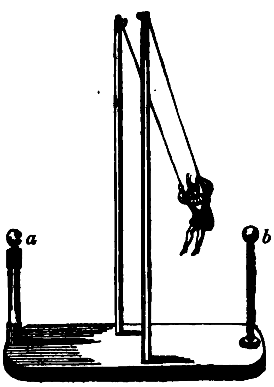


fig. 251.

The electrical see-saw, fig. 252, is a small strip of wood covered over with silver leaf or tinfoil, insulated on *a* like a balance. A slight preponderance is given to it at *a*, so that it rests on a wire having a knot *e* on its top; *d* is a similar metal ball insulated. Connect *d* with the prime conductor, and the see-saw motion commences.

Several philosophers conceiving that, instead of the barrel-shaped electrical-machine, one consisting of a circular disc would be more convenient and effective, contrived them of various substances. In 1785 Van Marum and Cuthbertson constructed one, now in the museum at Haarlem, which consists of two circular plates of glass 65 inches in diameter, both on the

same axis, and having four cushions 16 inches each in length. When in full action, a single spark from this machine would melt a leaf of gold, and

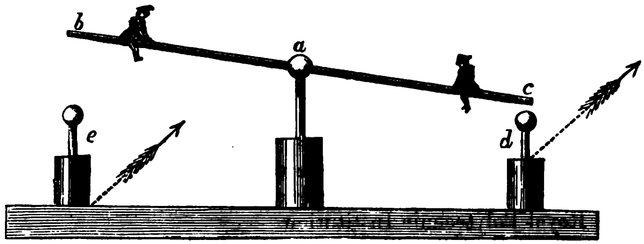


fig. 252.

it would attract a light substance at a distance of 38 feet; while from a pointed pin of metal a brilliant star would appear when 28 feet from the machine. The usual sensation of a cobweb spread over the face, when near to the plate of an electrical-machine, was felt from it at a distance of two feet; and the peculiar smell caused by electricity was very strong.

The plate-machine is now frequently used; and one of seven feet diameter, turned by a steam-engine, is sometimes exhibited at the Royal Polytechnic Institution. The largest yet made is at the Royal Panopticon of Science; this is ten feet in diameter; extraordinary results are antici-

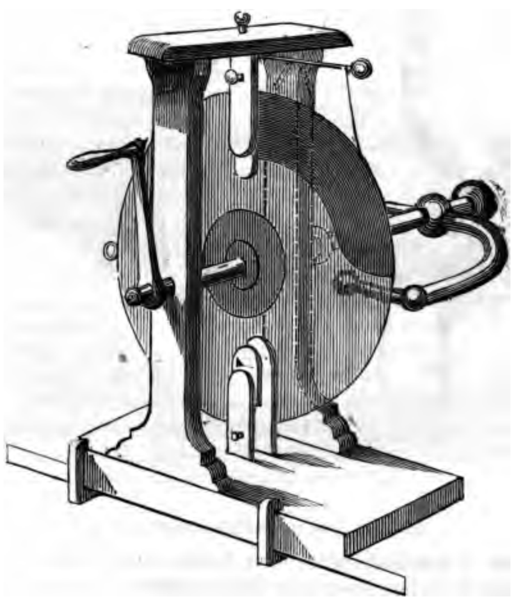


fig. 253. Plate Electric Machine.

pated from it. The accompanying diagram will illustrate the peculiar features of the machine. A large circular plate is caused to revolve rapidly, being supported upon two upright pieces of mahogany. The rubbers are

on each side, and the insulation is effected by two pillars of glass. The conductor is of metal, with two arms terminating in points, and supported by strong pieces of glass. A curved brass tube acts as the negative conductor on the opposite sides of the plates, and connects the cushions.

Great power can be obtained by these machines; and as their surfaces can be easily reached, they are kept more perfectly dry than those of the cylindrical form. Excellent and economical machines are now made by covering a disc of wood with a thin sheet of gutta-percha.

Electricity is as yet a young science, and every day brings forth some discovery in relation to it; one of the most remarkable is that of generating it from steam—a machine for which purpose has been used for some time at the Royal Polytechnic Institution.

A workman at Seghill colliery, near Newcastle-upon-Tyne, having to adjust a safety-valve in consequence of an escape of steam, was astonished on feeling a powerful spark of electricity when one of his hands was in the vapour, which proceeded from the boiler and the metal-work connected with it. Mr. Armstrong, a scientific gentleman at Newcastle, immediately commenced an investigation of the subject, and found that with an insulated brass rod, having at one end a ball and at the other a metal plate, obtained from it 60 to 70 sparks per minute; the ball being near the boiler, and the plate in the steam. This led ultimately to the construction of the hydro-electric machine.

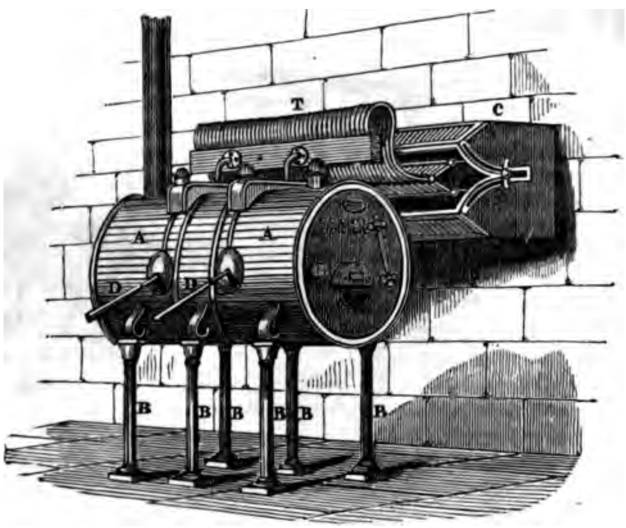


fig. 254. Armstrong's Hydro-electric Machine.

It consists of a cylindrical tubular boiler A A of rolled iron-plate cased in wood, 7 feet 6 inches long, one foot of which is occupied by a smoke-box. The furnace and ash-hole are within the boiler, furnished with a metal screen, which is applied to exclude light during some experiments. There are 46 bent iron tubes T, in form not unlike the figure of 2, rising above the boiler, and terminating in jets formed of partridge-wood. Either

half or the whole of the jets may be opened by means of levers that project from the sides of the boiler, D D. The boiler is insulated, and supported on stout columns of glass B B. A zinc case C having four rows of points is placed in front of the jets, which collects the electricity from the ejected vapour. When a large quantity of electricity is required, the points are placed within a few inches of the jets; and when long sparks are needed, it is moved to a distance of about two feet. The pressure at first is about 90 lbs. This electricity is remarkable for its intensity, as well as the enormous quantity produced in comparison with other frictional machines, but small, as will be afterwards shewn, in comparison with the galvanic-battery; its quick succession of sparks causes it to inflame shavings, paper, and gunpowder.

Electricity and lightning resemble each other: when the former is drawn off from bodies possessed of more than their natural share a smart report is given, electric clouds peal forth thunder; a vivid spark is seen from electricity, lightning illuminates the heavens; electricity darts along the best conducting particles of matter, lightning proceeds in a zig-zag way as moisture presents itself; electricity gives forth heat in its path, and lightning rends the sturdy oak, or breaks in pieces the steeple of stone, or melts a too thin or small metal conductor in its rapid career to the earth.

The best positions of safety during a thunder-storm are said to be, if out of doors, to take shelter under sheds, carts, low buildings, or the arch of a bridge; the distance of twenty or thirty feet from tall trees or houses should be chosen, for should a discharge take place, elevated bodies are most likely to receive it; and if the explosion follows the flash with great rapidity, it is evident that the electric clouds are near at hand, and a recumbent posture on the ground is the most secure. Avoid water, for it is a good conductor; and a man standing near a lake is not unlikely to determine the direction of the discharge. Within doors we are tolerably safe in the middle of a carpeted room, or standing on a double hearth-rug. The chimney should be avoided; gilt mouldings and bell-wires are equally dangerous. In bed we are quite safe; blankets and feathers being bad conductors, we are therefore to a certain extent insulated. It is injudicious to take refuge in a cellar, because the discharge is often from the earth to a cloud, and buildings sometimes sustain the greatest injury in the basement stories.

The thunder-house, fig. 255, is an amusing illustration of the use of a continuous conductor for carrying away the lightning. Franklin first proposed the erection of a lightning-conductor for the protection of tall buildings, by means of a metallic rod in perfect communication with the earth. A is intended to represent a board shaped like the gable end of a house, a piece of dry mahogany having been selected for the purpose, with B, a copper-wire, having a brass knob at the top, which terminates at D, but is made to come in close contact and pass on to C. The central portion D is so arranged with the wire fixed to it, that it can be taken out and placed crosswise. Arrange it now as in the cut, and then attach a piece of brass chain to the hook at C, and bring this in contact with the outside of a Leyden jar charged with electricity, and then with the discharging-rod send the charge from the jar to the brass knob; it will be seen that the charge will pass down without doing any perceptible

injury. Now place the square piece of wood D crosswise, so that the line of continuity may be broken in the copper wire, and again send another charge of electricity to the brass knob. The shock will now throw out the piece of wood with great violence; which may be considered as a very humble imitation of the effects of a stroke of lightning, the passage of which, when uninterrupted, passes quietly down, but when impeded it deals destruction around.

To measure the intensity of electricity, its quantity, forces, and effects, there are instruments called electroscopes and electrometers. In some instances the electrical tension is so weak, that its presence can only be detected by those delicate instruments. The electroscope shews when a body is in a state of electrical tension, and whether the free electricity it possesses be positive or negative; acting thus according to the universal law of electrical polarity, their excellence depends on having a good conductor that is attracted or repelled with great facility.

Cavallo's electrometer consists of two balls of cork or pith suspended to two very fine wires in a covered glass jar, which are attached to a conductor. Volta used fine straws in place of wires.

Bennett's gold-leaf electrometer is constructed on the same principle, but in place of the wires and balls are two fine strips of gold-leaf.

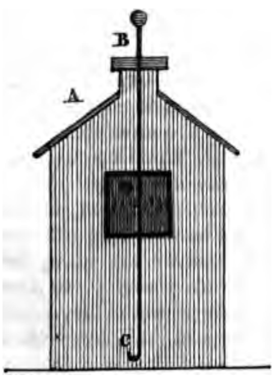


fig. 255.

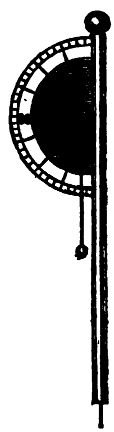


fig. 256.

Henley's quadrant electrometer, fig. 256, serves to measure the repulsive force of powerful electrical tensions, and is considered a necessary part of an electrical machine: it is placed in a small hole of the conductor. It consists of a graduated half-circle fixed to a conducting rod; from the centre of the circle proceeds a short reed on a fine axis, and having at its end a pith ball. The movement of the reed, from the ball of the conductor against which it rests, up the scale marks the amount of electricity.

An instrument known as the electrophorus, fig. 257, consists of a circular metal plate having a rim about a quarter of an inch deep at the edge, into which is poured equal parts of melted shell-lac, Venice turpentine, and resin; and a metal cover with a glass handle. The resinous plate is

held in a slanting direction, and hit sharply several times with dry warm fur or flannel; the cover is then placed on the plate, and on lifting it off by the handle it will be found to have a weak charge of negative electricity. Replace the cover and touch it with the finger, and then, on lifting it again and pressing the knuckle, a strong spark of positive electricity will be given. This may be repeated several times without again exciting the resinous cake, — indeed, under particular circumstances, such as a dry state of the air, for weeks afterwards. The electricity of the movable plate is in this case derived not in the way of charge from the resin, but is the result of the process of induction.

fig. 257.

Faraday used an electrophorus of shell-lac about an inch in diameter, and seven inches in length, fixed in a wooden stand, the shell-lac being concave at the top to hold a brass ball; when he demonstrated that inductive action taking place invariably through the intermediate influence of intervening matter, would be found to be exerted, not in the direction of straight lines only, but also in curved lines. The upper part of the stick of shell-lac was excited by friction with warm flannel, a brass ball suspended by silk was placed in the hollow at the top, and the whole arrangement examined by the carrier-ball and an electrometer. For this purpose the carrier was applied to various parts of the ball, the two were uninsulated whilst in contact or in position, then insulated, separated, and the charge of the carrier examined as to its nature and force. Of course whatever general state the carrier acquired in any place where it was uninsulated, and then insulated, it retained on removal from that place, and the distribution of the force upon the surface of the *inducteous* body while under the influence of the *inductric* was ascertained. The charges taken from the ball in this its uninsulated state were always vitreous, or of the contrary character to the electricity of the lac. When the contact was made at the under part of the ball *d*, the measured degree of force was 512 degrees, when in a line with its equator *c* 270 degrees, and when on the top of the ball *b* 130 degrees. Even in the position *e* the proof ball became inducteous, and at *a* it was affected in the highest degree, and gave a result above 1000 degrees.

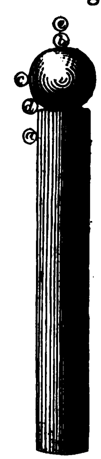


fig. 258.

The matter, fluid, or whatever we may please to term the mysterious force electricity, seems not to spread through the entire body of the thing that receives it, but to remain on the surface. To test this, in 1837 Faraday had a large chamber made coated with leaf-gold, and properly insulated; to this electricity was applied until sparks and pencils of light were thrown off. The philosopher then placed himself inside with candles and the most delicate electrometers, but within the chamber not the least effect was perceptible.

Smeaton, the celebrated engineer, covered a sheet of glass on both sides with thin metal, leaving a margin all around; then having applied electricity to one of the surfaces, he touched each side at the same time, and thus received a shock. Sir W. Watson, who had thrown great light on the subject, covered a jar on both sides with thin leaf-metal, leaving a portion near the neck bare; and this perfected what is now distinguished by the appellation of the Leyden Jar, fig. 259.

fig. 259.

A cylindrical glass jar is covered with tinfoil both inside and outside to within a few inches of the top, the uncoated glass forming the insulating part. The lid is made of baked wood, and inserted with sealing-wax; and a light metallic charging-rod extends about three inches out of the lid and terminates in a knob, and is in contact with the inside coating of the jar at the bottom.

When the knob of the charging-rod is placed near the conductor of the machine, sparks are emitted, which grow fainter as the jar is charged. The electricity on the outside of the jar and that of the inside are communicated to each other by means of the discharging-rod, represented in the wood-cut, which consists of two arms of brass bent, having at the ends round knobs, with a joint in the centre to open or close to the required distance. The handle is of glass, that it may be insulated.

When it is desired to discharge the electricity of the jar, one knob of the discharging-rod is brought in contact with the outer covering, and the other to the knob of the charging-rod, when the negative and positive electricity rush violently to each other, and with a loud report and vivid light equilibrium is restored. When we recollect that the hundreds of sparks that enter the jar from the prime conductor are discharged in one, we cease to marvel at the force and brilliancy of the discharge.

As the quantity of electricity is much greater when collected in a Leyden jar than that derived at any one time from the conductor, if a charge be sent through the human frame a violent shock is felt. When a hundred or more persons join hands, and the party at each end holds a chain or other means of communication, so instantaneously is the shock felt by all, that the unanimous shout of "Oh !" is in excellent time. The shock can be communicated at almost any distance without a perceptible difference of time.

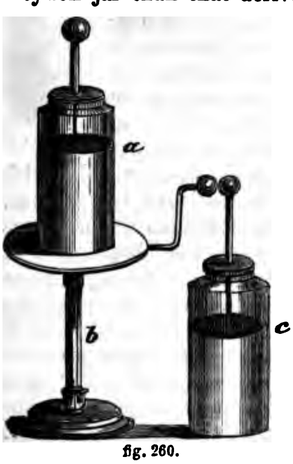


fig. 260.

The electricity that passes into the jar is vitreous, or positive, if taken from the prime conductor; that from the cushion resinous, or negative; but whichever electricity is passed into the jar, the opposite will be induced on the outside of the jar.

If a Leyden jar be *insulated*, that is, placed so that it shall have no communication with the ground, it will be incapable of

receiving a charge of any considerable amount. Let *a* be a Leyden jar standing upon a glass support *b*; it will receive no charge from the prime conductor, unless a conducting communication be made with its outside coating and the earth. If an insulated second jar be placed at *c*, the electricity which passes off from the outside coating of *a* will charge *c*, and for every spark which passes from the prime conductor to *a* a similar one will pass from *a* to *c*.

It therefore will be seen, that as the vitreous electricity is communicated to the interior coating, it will be necessary to remove the same quantity from the exterior, which would otherwise counteract the resinous electricity by which the charge is sustained. This can only be effected by placing it in connection with the earth or the coating of another jar.

By placing together several coated jars and uniting their charging-rods, and also connecting their outer surfaces by a proper base or by chains, then when charged they act as one jar; which combination is called an electrical battery. M. Marum formed a battery of one hundred jars, each thirteen inches in diameter, two feet high, the whole consisting of above 550 square feet of coated glass. After charging this tremendous battery, he passed it through steel bars nine inches long, half an inch wide, and one-twelfth of an inch thick, which rendered the bars intensely magnetic. The hardest wood was rent to pieces, iron-wire was dispersed in red-hot balls, and tin-wire became a cloud of blue smoke, which rained down red-hot globules. This would destroy a dog instantly if passed through the head and spine.

As these large quantities of electricity are chiefly used to act upon inorganic bodies, the conductors are so arranged that the body subjected to the influence forms a part of the circuit. For this purpose there is an instrument contrived, called a universal discharger.

This consists of two rods fixed on pillars of glass, on the top of which are universal joints, the rods being so placed in the sockets as to be lengthened or shortened. In the centre is an insulating table on a glass rod, with a contrivance for lowering or heightening it. The circuit is completed by the rods being connected with the negative and positive portions of the battery; and the object to be acted on is placed on the little table between the ends of the rods.

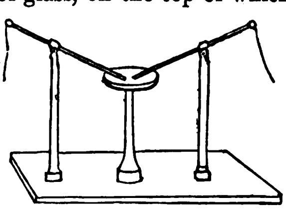


fig. 261.

A charge from a battery fired through many sheets of paper will cause a hole to be made most perfectly, and produce a smell similar to phosphorus. In this experiment, if the paper be examined, a burr on both sides will be seen, evidencing that the two electricities have passed in opposite directions.

A leaf of gold placed between pieces of common window-glass will be so forced into it, as to change the body colour of the glass into that of purple.

If a small phial half full of salad-oil, having a slight piece of wire passed through the cork and so bent within the phial as to touch the glass just below the surface of the oil, and a spark be taken from a charged conductor, while a thumb is placed opposite to the point of the wire, the electricity will make a hole in the phial in its journey to the thumb.

A thousand exceedingly small and perfectly round holes may thus be formed.

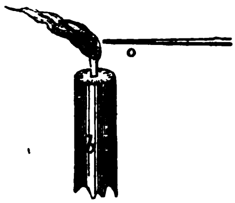


fig. 262.

If, when the machine is at work, a pointed brass-wire about six inches long, having a small brass ball *o* at its extremity, and the other end connected with the extremity of a prime conductor, be directed against the flame of a candle *b*, the flame will be blown away as if wind from a strong bellows had been used.

A gold ground is sometimes given to paper or silk by first cutting out in slight card-board the pattern wished; this being placed on the silk or paper, gold-leaf is laid over the parts cut out, an uncut card-board is put on as a cover, then the whole pressed and electricity passed through it. On opening it out the leaf-gold is found to have formed a ground the shape cut out in the card-board.

It may be observed in a wire that is not large enough to allow a certain charge to run freely through it, that it becomes red-hot; and if the wire were smaller still, it would be melted. This shews that heat is evolved by electricity according to the resistance met with. Sparks drawn from ice have the same powers as those from other apparently more favourable bodies.

Loaf-sugar, when submitted to electricity, presents a beautifully luminous appearance, that is retained for some time.

Common vermilion, which is formed of sulphur and mercury, when placed on the universal discharger-table and electricity passed through it, causes the mercury to be separated and appear in its metallic state.

The following also are exemplary of the chemical changes produced by electricity:

Camphor loses its peculiar smell, and is some time before it regains it.

Oxides of metals may be converted into their original condition; and metals may be oxidised.

Glass may be stained by the oxide of tin as if by the metal itself.

Various fluids may be decomposed and separated into their simple elements.

Thus does this mysterious agent appear to universally pervade the aerial, fluid, and solid substances of creation, and to be one of the ever-ready agents in the operations of nature. In the hands of man the most obstinate of substances can be decomposed; water and other bodies can be resolved into their constituent elements, and again restored to their former states. Thus with the divine gift of mind man acquires some of nature's secrets and mimics her workings.

In the works of the most ancient writers there are circumstances related that evidence atmospheric electricity being noticed at the periods at which they wrote. But it was not until the commencement of the eighteenth century such an idea was broached by Dr. Wall, that electricity and lightning were of the same nature. This notion, thirty years afterwards, was reiterated by Grey; and in 1745 Nollet writes, in his *Leçons de Physique*, of "thunder and lightning being in the hands of nature what electricity is in ours." In 1749, Franklin suggested the idea of explaining the phenomena of thunder-gusts and of the aurora borealis upon electrical principles; and in the same year he conceived the asto-

nishingly bold and grand idea of ascertaining the truth of his doctrine, by actually drawing down the lightning by means of sharp-pointed iron rods raised into the region of the clouds. During the building of a church at Philadelphia, while waiting for the erection of the spire to try the experiment, he became tired of the delay, and conceived he might accomplish his object by means of a common kite. Accordingly, in the summer of 1752, he prepared one by fastening two cross-sticks to a silk handkerchief, which would not suffer so much from rain as paper. In the upright stick was affixed an iron point. The string was as usual of hemp, except the lower end, which was silk. Where the hempen string terminated a key was fastened. With this apparatus, on the appearance of a thunder-storm, he went out on to a common, accompanied by his son, to whom alone he communicated his intention, as he knew it was but a step from the sublime to the ridiculous. He placed himself under a shed to avoid the rain, his kite was raised, a thunder-cloud passed over it, and no sign of electricity appeared. His heart palpitated, the fate of his grand theory seemed sealed; and when almost despairing of success, suddenly he observed some of the loose fibres of the string move to an upright position from repulsing each other. He now presented his knuckle to the key, and received a strong spark. Such at this moment was the intensity of his feelings, that he heaved a deep sigh, conscious that fame would now record his name in the archives of genius. Rain having fallen, by which the conducting power of the string became increased, repeated sparks were drawn from the key, a phial was charged, a shock was given, and other confirmatory experiments were performed.

The identity of lightning and electricity had, however, been proved a short time before Franklin's celebrated kite experiment, by a French philosopher, who obtained sparks from an elevated and insulated pointed rod erected near Paris; but it was Franklin who suggested the plan.

M. de Romas, of Nerac in France, on the 7th of June, 1753, repeated the kite experiment of Franklin; he raised the kite to a height of 550 feet, and had a copper-wire wound round the string, which was attached to an insulated iron tube. The flashes were extraordinary in size, and the noise of their explosion was heard at a great distance, while the people near felt the peculiar sensation like spiders' webs spread over their faces. A roaring sound was heard, and straws were attracted and repelled from the string, while the kite appeared surrounded by a bright light.

These experiments of Franklin aroused the attention of philosophers in all parts of the world. Professor Richman of St. Petersburgh bade fair to add much to the knowledge of the subject, when engaged one day making experiments with a charged rod at the top of his house, a flash struck his head, and instantly deprived him of life.

The electricity of the atmosphere, like the ocean, appears to be in a constant state of commotion, being at full tide just after the rising and setting of the sun, and lowest at noon and midnight. It is generally positive, but during humid storms, and influenced by certain clouds, it becomes negative. During rain, snow, sleet, hail, thunder, and fogs, it varies rapidly from one condition to another.

Lightning is produced by the clouds becoming overcharged with electricity, and therefore making sudden efforts to restore their equilibrium.

The roll of thunder that we hear is an echo, similar to that which is heard when a gun is fired at sea and a cloud is hovering near.

Professor Thomson, in his *Outlines of the Source of Heat and Electricity*, says, "In thunder-storms the discharges usually take place between two strata of clouds, very seldom between the clouds and the earth; but that they are sometimes also between clouds and the earth cannot be doubted. These discharges sometimes take place without any noise. In that case the flashes are very bright; but they are single flashes, passing visibly from one cloud to another, and confined usually to a single quarter of the heavens. When they are accompanied by the noise we call thunder, a number of simultaneous flashes of different colours, and constituting an interrupted zig-zag line, may generally be observed stretching to an extent of several miles. These seem to be occasioned by a number of successive or almost simultaneous discharges from one cloud to another, these intermediate clouds serving as intermediate conductors, or stepping-stones for the electric fluid. It is these simultaneous discharges which occasion the rattling noise which we call thunder." We consider when no noise is heard, it is the distance alone that prevents it, and that there can be no lightning without thunder any more than we can take a spark from an electric-machine without a snapping noise.

Often, most especially in summer, will large drops of rain fall with such force to the ground as is inconsistent with the idea of being merely the result of gravity. The fact is, those globules of rain are like the little pith-balls before-mentioned charged with electricity, which are repelled from the clouds and attracted to the earth.

Mr. Sturgeon's kite experiments appear to have been very extensive. "I have made," says he, "upwards of five hundred electric-kite experiments, under almost every circumstance of weather, at various times of the day and night, and in every season of the year. I have experimented on Shooter's Hill, and on the low lands on the Woolwich and Welling sides of it; and the experiments in the three different places within an hour of each other. I have done the same on the Chatham lines and in the valley on the Chatham side of them; on Norwood Hill and in the plain at Addiscombe; also at the top of the Monument in London, and on the top of some of the high hills in Westmoreland and in the North Riding of Yorkshire; and in every case I have found the atmosphere *positive* with regard to the ground. I have floated three kites at the same time at very different altitudes, and have uniformly found the highest to be *positive* to the other two, and the centre kite *positive* to that which was below it; consequently the lowest was negative to the two above it, but still positive to the ground on which I was standing. I have made more than twenty experiments of this kind, and the results (with the exception of electric tension) were invariably the same: shewing most decidedly that the atmosphere in its undisturbed electric state is more abundantly charged than the earth; and, as far I have been able to explore it, still more abundantly in the upper than in the lower strata."

Mr. Crosse, so well-known for his researches in this branch of science, was in the habit of collecting the electricity of the atmosphere by means of wires supported and insulated on poles fixed on some of the tallest trees in his garden. The wires were insulated on the poles by means of a funnel, represented in fig. 263. It was made of copper, about four inches in dia-

meter and eleven inches in length; into a cavity or socket of about two inches deep, formed at the end of the closed funnel, was firmly cemented a stout glass rod of sufficient length to reach to the open end of the funnel, where was mounted, by means of strong cement, a metallic cap and staple. The latter received the hook of a strong wire which passed through a circular plate of copper placed about four inches from the mouth of the funnel, and terminated in a hook on which one end of the exploring-wire was fixed. Such funnels were easily raised to the tops of trees or poles by an arrangement of pulleys. They were then taken, by means of conducting-wires, to a battery placed inside the room, consisting of fifty jars. In this way Mr. Crosse frequently collected sufficient electricity to charge and discharge this battery twenty times in a minute, accompanied by reports as loud as those from a good-sized cannon. When the middle of the thunder-cloud was over-head, he was often enabled to fuse into red-hot balls 30 feet of iron wire in one length, and 1-270th of an inch in diameter; and a crashing stream of discharges took place between his large brass balls, the effect of which, he says, "must be witnessed to be conceived possible."

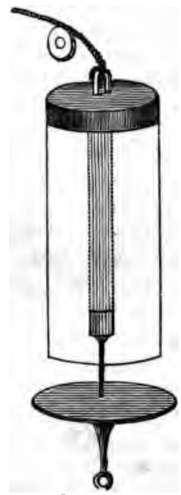


fig. 263.

It is curiously illustrative of the economy of nature, that the sharp points of the vegetable kingdom are more powerfully attractive of electricity than the sharpest point of metal that can be made by man's ingenuity; for if a piece of pointed iron and a blade of grass be held near to a prime-conductor, so that each point becomes luminous, and then gradually be drawn back, the iron will lose its luminosity long before the point of the grass. The sensitiveness of the point of a blade of grass may be seen in any part of an apartment where electricity is being evolved. Instances have been observed in green-houses where two pointed-leaved plants have covered another plant and drawn from the air all the adjacent electricity, by which the more humble and less prickly plant in the shade has perished, solely from want of this vital principle. This is another instance of the singularly careful arrangement of the entire mechanism of nature, in which the film is but clearing off man's mental eyes to its simplicity, beauty, and divine origin.

The aurora borealis or northern lights, that so magnificently illume the heavens on a scale of immense magnitude, is admitted without hesitation to be an electrical phenomenon, as electricians can most successfully imitate it on a small scale. It is considered to be the flashing of electricity through rarified atmospheric air at different heights from the earth's surface. Poor Captain Franklin found, from observations at the north pole, that the aurora was at a less elevation than that of denser clouds; this was confirmed afterwards by Parry.

If a tube, fig. 264, two feet long, having a brass ball at each end projecting into the inside, be nearly exhausted of its air, on connecting b with the prime-conductor and a with the

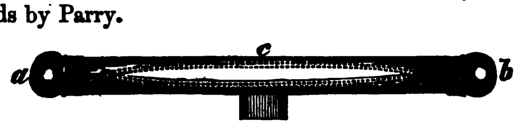


fig. 264.

earth, *b* becomes positive and *a* negative; the two electricities are then discharged, and there is all the appearance of the aurora borealis,—the faint twilight, streamers of white and coloured light, the silvery beams gliding swiftly along, the beautiful strings of light moving about and breaking forth into new beauties, playing, as it were, in fairy sylph-like forms in exuberance of delight. According to the rarity of the air in the tube, so are the variety of colours.

The aurora borealis generally appears in northern latitudes in cold seasons, tinted with green, purple, violet, or red, and so transparent that the stars are seen through it. In Siberia it is sometimes accompanied by a crackling noise, similar to that when turning an electrical-plate without conductors. This alarms the poor ignorant boors, who endeavour to hide themselves, and are in the utmost terror.

The meteors that are so frequently seen about the rigging of vessels are to be referred to the effect of points on the electricity of the atmosphere.

Waterspouts, whirlwinds, and earthquakes are thought by some investigators of this branch of science to be the effect of electrical action. There can be no doubt that such action does accompany these different phenomena, still there is no evidence that electricity is the producing cause; and in all matters of science the utmost care must be taken not to be satisfied with mere conjecture, more especially when other physical causes appear to approach nearer to the truth.

Electricity is a mode of defence or destruction to their prey that has been bestowed upon some animals, the most remarkable of which is the raia torpedo, a flat-fish, seldom twenty inches long, found on the coasts of Europe, fig. 265. The electrical powers are placed on each side of the gills, where they extend from the upper to the lower surface, covered by the skin of the body. When one hand is placed on the upper and the other on the lower surface, a smart shock is felt; the organs of electricity answering to the positive and negative sides of a Leyden jar. This natural electricity can be withdrawn from the animal by means of a conductor, and a shock is felt through a circuit formed by several persons joining hands. No spark can be obtained, nor can electric attraction and repulsion be pro-

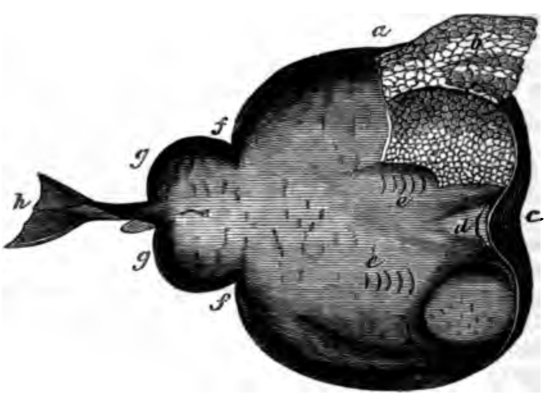


fig. 265. The Torpedo.

duced; but strong solutions of common salt, nitrate of silver, and super-acetate of lead have been decomposed by its electrical powers, and steel magnetised. When the torpedo sends forth a shock it depresses its eyes, contortions of the body follow, and it appears to have a control over the power.

In the accompanying figure *a* represents the dorsal fin; *b* part of the skin turned over, shewing the right electric organ, white pliant columns resembling a small honeycomb; *c* the nostrils, in a crescent form; *d* the mouth, which has several rows of small teeth; *e e* the ten bronchial apertures; *ff* outer margin of the greater lateral fin; *gg* two smaller fins; *h* the tail fin.

The gymnotus, or electrical eel, fig. 266, is an inhabitant of the fresh-water lakes and rivers of the warmer regions of America and Africa. Its body is smooth and without scales, a long ventral fin extends from behind the head to the extremity of the tail; the mouth is armed with sharp teeth, and projecting into it are numerous fringes, that from their nature appear to serve a purpose in respiration; the gullet is short, terminating in a capacious stomach; the whole cavity of the abdomen is not more than seven inches long; besides the alimentary canal, the heart, liver, and upper part of the air-bladder. The rest of the animal is made up of the electrical organs and muscles of progression, together with an air-sac, which runs beneath the spine the whole length of its body. They are about six feet in length.

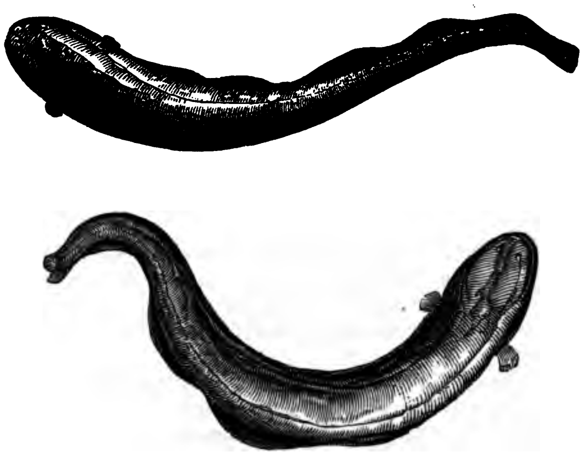


fig. 266. The Gymnotus.

The skin being turned over, the two electrical organs are seen on each side. They are of two parts: flat partitions or septa, and cross divisions between them. The outer edges of these septa appear in parallel lines nearly in the direction of the longitudinal axis of the body; they are thin membranes nearly parallel to one another, their breadth nearly the semi-diameter of the body, but of different lengths, some being as long as the whole organ.

In the accompanying figure, 267, *a* represents the head; *b* the cavity

of the belly; *c* the back when the skin is not removed; *d d* the ventral fin; *e e* the skin turned back; *f f* the lateral muscles of the fin; *g g g* the large electrical organ; *h h* the small organ.

fig. 267.

When small fishes are put into the water in which the gymnotus is kept, it will first stun, or perhaps kill them as if by a stroke of lightning, and if hungry it will then devour them. If the stunned fish be removed to another vessel of water, it will speedily recover.

The gymnotus seems to know whether substances are conductors, as it will only exert its electrical powers on those that are so.

A powerful shock is obtained when one hand is placed near the head and the other near the tail. Faraday fitted a kind of saddle upon one for the purpose of experiments, and found that a galvanometer not very delicate was affected to the extent of 40 degrees; and the electric current was always found to be from the anterior parts of the animal through the galvanometer wire to the posterior parts. The former were, therefore, for the time externally positive, and the latter negative: an annealed steel needle, placed in a little helix of twenty-two feet of silked wire wound on a quill, became a magnet; decomposition of iodide of potassium was easily obtained. On comparing the middle part of the fish with other portions before and behind it, it was found that within certain limits the condition of the fish externally at the time of the shock appears to be such, that any given part is negative to other parts anterior to it, and positive to such as are behind it.

A single medium discharge from the animal is calculated to be equal to the electricity of a Leyden battery of fifteen jars, containing 3500 square inches of glass coated on both sides and charged to its highest degree; and of this force it can give double and triple shocks following instantaneously.

M. Gassoit fused some slips of gold leaves, scintillating in the most beautiful manner, with the electricity from one of those eels.

When a number of persons dip their hands into the vessel in which one of those animals is kept, they all receive a shock, differing in intensity according as they are situated with regard to the direction of the current.

A gymnotus, intended to be sent to this country, was killed by a water-rat, notwithstanding its extraordinary powers; but this may be accounted for by remembering that the body of the rat is perfectly insulated, for even when he dives under water not a particle of the liquid adheres to him, and his non-conducting fur, and the air which it contains, rendered him impervious to the electricity of the eel.

On this remarkable fish Daniell says: "Never was there a more

tempting field of research, or a higher reward offered for its successful cultivation, than that which is presented by *animal electricity*. In these electric fish we behold *nervous* power converted into electric force; it cannot be doubted that the *converse* of this is possible. We are, however, only on the threshold of this inquiry of surpassing interest."

VOLTAIC ELECTRICITY, OR GALVANISM.

Swammerdam, who devoted himself to the anatomy of insects, in 1678, two years previously to his death, exhibited before the Grand Duke of Tuscany an experiment, shewing the contraction of a muscle by bringing a nerve connected with it in contact with a silver and copper wire. The sensation and peculiar saline taste that results from placing on the tongue a piece of silver, and under it a piece of lead or zinc, whenever the edges of the metals are brought into contact, was described in a work by Sulzer, entitled the *General Theory of Pleasure*, published in 1767.

These fortuitous circumstances, however, although it is as well to record them, are no connecting link in the grand discoveries we are about to enter upon. They are mere facts, and did not call forth severer investigation, but passed unheeded. The fame of Galvani, professor of anatomy in the university of his native city, Bologna, even if he were aware of the previous discoveries, suffers from them no deterioration.

Arago writes, "It may be proved that the immortal discovery of the galvanic pile arose in the most immediate and direct manner from a slight cold with which a Bolognese lady was attacked in 1790, for which her physician prescribed the use of frog-broth." The *Encyclopædia Britannica* states, "When one of Galvani's pupils was using an electrical machine, a number of frogs were lying skinned on an adjoining table for the purpose of cookery. The machine being in action, the young man happened to touch with a scalpel the nerve of a leg of one of the frogs, when, to his great surprise, the leg was thrown into violent convulsions." Dr. Lardner, after giving the usually-received account of Galvani's discovery, writes, "This was the first, but not the only or chief part played by *chance* in this great discovery. Galvani was not familiar with electricity; luckily for the progress of science he was more an anatomist than an electrician, and beheld with sentiments of unmixed wonder the manifestation of what he believed to be a new principle in the animal economy; and fired with the notion of bringing to light the proximate cause of vitality, engaged with ardent enthusiasm in a course of experiments on the effects of electricity on the animal system. It is rarely that an example is found of the progress of science being favoured by the ignorance of its professors. *Chance* now again came upon the stage. In the course of his researches he had occasion to separate the legs, thighs, and lower part of the body of the frog from the remainder, so as to lay bare the lumbar nerves. Having the members of several frogs thus dissected, he passed copper hooks through part of the dorsal column which remained above the junction of the thighs, for the convenience of hanging them up till they might be required for the purpose of experiment. In this manner he happened to suspend several upon the iron balcony in front of his laboratory, when, to his inexpressible astonishment, the limbs were thrown into strong convulsions. No electrical machine was now present to exert any influence."

How satisfactorily circumstantial are the particulars given in relation to the great discovery, and worthy the importance of the subject! The frog-broth and pupil with his scalpel form admirable subjects for the artist's pencil; they are romantic details that cling to the imagination. Then how enviable to laborious genius, that, instead of days and nights of study, years of experiments, varying in success and disappointment, yet filled with hope from occasional glimmerings of truth, and a firm conviction lending energy to perseverance,—that *chance* should save all, and present at once a fact to immortalise the observer! This is a lesson of modern times that should render us cautious of all history, as the entire account is a fable. Galvani was long and ardently a student in electrical science; so devoted was he to the subject, so absorbed in the discovery of its mysteries, that self was forgotten, and in his enthusiasm, in 1786, he grasped in his hands the rod of an insulated atmospheric conductor at the very time when lightning was darting from the clouds directly over his head. Fortunately for science and for himself, the rash and daring experiment was unattended by a fatal result.

It is on record that, twenty years before the publication of his *Commentary*, Galvani was engaged in experiments on electricity, and that he used the nerves of a frog from finding them the most delicate test even of atmospheric electricity.

Dr. Wilkinson, of Bath, in his *Elements of Galvanism*, published in 1804, proved this discovery of Galvani to be correct; and he calculated that the irritable muscles of a frog's leg were no less than 56,000 times more delicate as a test of electricity than the most sensitive condensing electrometer. He found that two pieces of zinc and silver, each presenting a superficial surface of $\frac{1}{100}$ inch, produced violent contractions in the leg of a prepared frog; whilst two circular plates of zinc and copper required to be brought twenty times in contact with the condenser before any sensible divergence of the gold leaves of an electrometer was produced. By comparing the area of these plates, multiplied by the number of contacts, with the superficial surface of the minute pieces of zinc and silver employed to affect the frog's leg, he arrived at the above conclusion.

Professor Matteucci has fully corroborated this experiment, and availed himself of it by constructing a *frog galvanoscope*.

In the collection of Galvani's works, recently published by the Academy of Sciences of Bologna, his *Experiments on the Electricity of Metals* are dated September 20, 1786. His other scientific essays on his various discoveries are numerous. It was not until the year 1791 that the discovery of what is termed galvanism was published to the world by its author.

Galvani shewed that if a metallic arc be constructed of two different metals joined together, and one extremity of it touched the nerves and the other the muscles of a frog, a contraction or convulsion took place; that the metals used should be those least liable to oxidation; and that in the experiments the electrical machine was unnecessary. He believed that animal electricity existed as a nervous fluid held in the interior of a muscle. If the legs of a frog are left attached to the spine by the large nerves leading to the thighs, and then a copper and zinc wire, soldered together at one end, be applied, that is, one wire to the nerves and the other to the muscles, a violent action will take place.

If part of the nerve be wrapped up in tin-foil, or be laid only upon zinc, and a piece of silver be laid with one end upon the muscle, and the other upon the tin or zinc, the limb will be put in motion.

Place two wine-glasses full of water near each other, and put the skinned thighs and legs of a frog into the water of one glass, and lay the nerve covered with tin-foil over the edges of the two glasses, and just touching the water; let now a communication be made between the water in the glasses by means of silver, or by putting the fingers of one hand into the water of the glass that contains the legs, and holding a piece of silver in the other; if then you touch the coating of the nerves with it, the legs will be so violently excited as sometimes actually to jump out of the glass.

If a small piece of sheet-copper have placed on it a piece of zinc, and then a leech, worm, or snail be set to crawl upon the zinc, when the animal touches the copper it will suddenly shrink, and ultimately carefully avoid it; and hence is a prisoner, not daring to attempt to escape. From this circumstance, Mr. Noad proposed to protect plants from worms and slugs, by encircling the stem with rings of zinc and copper soldered together, which has proved successful.

If a live flat fish have a piece of tin-foil pasted on its back and then be placed on a plate of zinc, a communication being made between the tin-foil and zinc, convulsive motions will take place in the animal.

A piece of zinc put as high as possible between the upper lip and gums, and a piece of silver upon the tongue, when brought into contact a disagreeable metallic taste will be produced, and by directing the eye downwards a flash of light will be visible.

If a piece of tin-foil be placed over the ball of one of the eyes, and a silver teaspoon in the mouth, upon bringing the handle of the latter in contact with the tinfoil, a faint light will be seen.

VOLTAISM.

The announcement of the discoveries by Galvani aroused the attention of scientific men all over the world, who repeated the experiments of the Bolognese philosopher. Amongst others was Volta, who for thirty years occupied the chair of natural philosophy in the University of Pavia, and whom Napoleon did himself the honour to create a count and senator. Volta combated the opinions of Galvani as to the different parts of an animal being in opposite states of electricity, which the application of the metallic arc restored to an equilibrium. He considered that the metallic arc developed electricity which irritated the nerves, sometimes producing the sensation of light or taste, sometimes exciting contractions. In August 1796 he discovered that which has rendered his name immortal, the Voltaic Pile, a description of which was published in 1800, in the *Philosophical Transactions.* It consisted of alternate layers of silver or copper and zinc plates arranged in regular order, one above another, with moistened flannel or pasteboard between each pair. By wetting the flannel or pasteboard with salt and water, the strength of the shock, which is felt on moistening the fingers and touching each end, is increased.

De Luc formed what is called an Electric Column, or dry pile, which consisted of small round pins of silver, zinc, and paper, placed alternately. About a thousand of these being inserted in a dry glass tube, a brass cap at each end screws them up tight. The centre of the pile is neutral, but the ends are in opposite electrical conditions. The late Mr. Singer

improved upon this by placing together about twenty thousand series of silver, zinc, and double discs of writing-paper; from this bright sparks could be produced, thin wire melted, and shocks received.

Many valuable and important improvements in the construction of the apparatus for generating voltaic power have been made by Cruickshank, Wollaston, Daniell, Smee, Groves, and Bunsen, but the details would occupy too much space to describe.

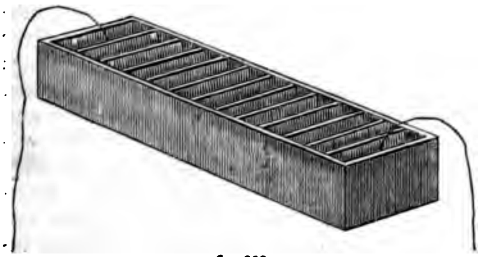


fig. 268.

The general principle of Cruickshank's battery, however, consists in having a wooden trough lined with pitch, into grooves of which, cut in the sides, are placed in an upright position metallic plates of zinc and copper alternately of any dimensions, and between each division is poured an exciting liquid consisting of diluted acid. From each end proceeds a wire, and the zinc end of the trough is found to be positive, and the copper end negative electricity, fig. 268.

It is found by experience that the *intensity* of the electric force is not increased by enlarging the size of the plates; which, however, adds to the *quantity* of electricity excited. Thus a few large plates are used when heating effects are required on bodies that are good conductors; and a considerable number of smaller plates are employed to effect chemical decomposition and to communicate shocks to animal bodies, which are but imperfect conductors of electricity.

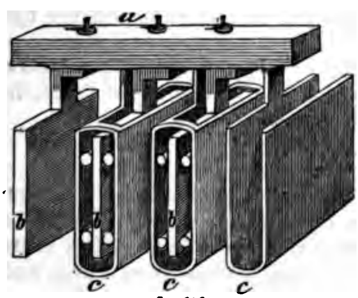


fig. 269.

Wollaston's voltaic battery, fig. 269, consists principally in the arrangement of doubling the copper plates *ccc*, so as to expose them to both surfaces of the zinc *bbb*. The plates are screwed to a bar of wood *a*; pieces of wood or cork are placed between the zinc and copper surfaces to prevent their contact; they are then placed in a trough.

To keep the battery in perfect action, it will be necessary from time to time to clean the zinc plates from the oxide which accumulates upon their surfaces; brushing them over with a little muriatic acid or nitrate of mercury will answer the purpose best, and secure a greater permanency of action. The common *Voltaic Pile*, on account of the loss of moisture, generally loses its electrical action in a few days, and this cannot be renewed without the trouble of reconstruction; but by Wollaston's contrivance, which becomes active on merely filling the cells with the proper acid or saline fluids, much trouble and time is saved.

Mr. Grove's batteries are generally admitted to be the most powerful. They are constructed out of a stoneware porous vessel divided into partitions, into each of which zinc plates, with a sheet of platinum between the two, are placed in a separate cell, and the whole connected together with

clamp screws. Common rolled zinc, one-thirtieth of an inch thick and well amalgamated with nitrate of mercury, may be employed. On the zinc side, or into the porous vessels, is poured a solution of either muriatic acid, diluted with from two to two and a half water; or, if the battery be intended to remain a long time in action, of sulphuric acid, diluted with four or five parts of water; and on the platinum side, concentrated nitro-sulphuric acid, formed by previous mixture of equal measures of the two acids. The apparatus should be provided with a cover containing lime, to absorb the nitrous vapour.

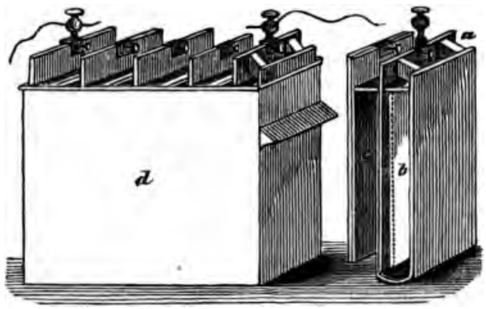


fig. 270.

The accompanying figure represents the complete battery, and the first set of plates removed from the porcelain trough *d*, shewing very clearly the arrangement: *a* is the bent zinc plate, *b* the insulated platinum plate in its porous cell, *c* the next platinum plate, connected by means of a binding-screw with the zinc at *a*.

One of the great advantages of the voltaic over the frictional electricity arises from the regularity with which it acts and the duration of its action, from whence there can be made experiments for the solution of many interesting subjects. In fact, very few compounds can resist a lengthened discharge from the apparatus. Davy having noticed that oxygen and most of oxy-acids were resolved to the positive end, and hydrogen and alkalis to the negative end, he suspected, and at length proved, that all alkalis contained inflammable matter: his discoveries, announced in 1807, opened out a new era in chemical knowledge.

The arrangement of different bodies at different ends of the wires communicating with the battery is shewn in the following simple experiment: if a glass tube bent in the form of the letter V be filled with distilled water, and corked at each end, then two pieces of platinum wire be passed through the corks and allowed to reach within an inch or two of each other in the tube, and the other ends of the wires be connected, the one at the positive and the other at the negative end of the battery, a continued stream of bubbles of gas will proceed from the negative wire to the end of the tube, and will be found to be hydrogen or inflammable gas, and that from the positive wire will accumulate at the other end of the tube and be pure oxygen.

In Davy's paper in the *Philosophical Transactions* on "Some Chemical Agencies of Electricity," he gives the following extraordinary experiment on the passage of acids, alkalis, &c., by the influence of the electric current, through solutions of substances.

"An arrangement was made, consisting of three vessels, fig. 271, containing as many different fluids; a solution of sulphate of potash was placed in contact with the negatively electrified point N, pure water was placed in contact with the positively electrified point P, and a weak solution of ammonia was made the middle link of the conducting chain, so that no sulphuric acid could pass to the positive point in the distilled water without passing through the solution of ammonia; the three glasses were connected together by pieces of amianthus. A power of 150 pairs was used; in less than five minutes it was found, by means of litmus-paper, that acid was collecting round the positive point; in half an hour the result was sufficiently distinct for accurate examination.

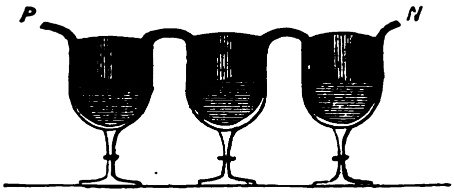


fig. 271.

"The water was sour to the taste, and precipitated a solution of nitrate of barytes.

"Similar experiments were made with solution of lime and weak solutions of potash and soda, in place of the ammonia, and the results were analogous. With strong solutions of potash and soda a much longer time was required for the exhibition of the acid; but even with the most saturated alkaline lixivium; it always appeared in a certain period. Muriatic acid from muriate of soda, and nitric acid from nitrate of potash, were transmitted through concentrated alkaline menstrua under similar circumstances. When distilled water was placed in the negative part of the circuit, and a solution of sulphuric, muriatic, or nitric acid in the middle, and any neutral salt, with a base of lime, soda, potash, ammonia, or magnesia, in the positive part, the alkaline matter was transmitted through the acid matter to the negative surface, with similar circumstances to those occurring during the passage of the acid through alkaline menstrua; and the less concentrated the solution, the greater seemed to be the faculty of transmission."

These and similar experiments excited the utmost astonishment in the scientific world; for the natural affinities of substances seemed partially suspended and destroyed. As yet no clear and determinate explanation has been given; all we know is, that the wires have the power of collecting around them the minutest particles of a substance.

One of the most patient investigators in electro-chemical science was the late Mr. Crosse, whom Dr. Buckland introduced to the British Association, at Bristol, in 1836, as "a philosopher who had made great discoveries by the use of a brick with a hole in it immersed in a pail of water." This gentleman, by keeping up the action of a battery for months on different substances, produced an extraordinary variety of minerals. Mr. Noad, in his excellent *Lectures on Electricity*, gives the following account of one of the experiments he saw at Mr. Crosse's mansion: "In a large, common, glazed salting-pan, filled with the spring-water of the country, a common red-brick was laid horizontally, each end resting on a half-brick of the same sort. The two ends of the brick were connected respectively with the positive and negative terminations of a sulphate of copper battery of nine pairs of nine-inch plates; the upper surface of the

brick was covered with clear river-sand. At the termination of a quarter of a year the apparatus was taken apart, and the following observations were made: On attempting to lift the whole brick from the two half-bricks that supported it, it was found, that while the positive end was easily removed from the brick below it, the negative end required some little force to separate it from its support; and when the two were wrenched asunder, it was observed that they had been partially cemented together by a tolerably large surface of beautiful snow-white crystals of arragonite, thickly studding that part of the brick in groups, the crystals of each radiating from their respective centres. Here and there were formed, in some of the little recesses in the brick, elevated groups of needle arragonite, meeting together in a pyramidal form in the centre; while in the open spaces between were some exquisitely-formed crystals of carbonate of lime, in cubes, rhomboids, and more particularly in short six-sided prisms with flat terminations, translucent and opaque, sufficiently large to determine their form without the use of a lens. The positive end of the brick, and that which supported it, were also covered with crystals, much smaller, and apparently of a different nature. On emptying the water from the pan, there was found at its negative end, at the bottom, a very large quantity of snow-white carbonate of lime to the extent of some ounces in weight, in the form of a gritty powder in minute crystals. Three-fourths of the whole interior of the pan were covered with myriads of crystals of carbonate of lime, so firmly adhering to the pan as not to be separated without the aid of an acid."

It would seem strange, when mentioning Mr. Crosse and his experiments on crystalisation, to pass over in silence a circumstance that has excited much discussion. Mr. Crosse was endeavouring to form crystals of silica, when he observed the gradual growth of some insects from the middle of the electrified stone, which on the twenty-sixth day became perfect; and in a few weeks there were hundreds. Fig. 272 shews a magnified view of one of these. The discoverer writes: "I have never given an opinion as to the cause of their birth, and for a very good reason—I was unable to form one. The most simple solution of the problem which occurred to me was, that they arose from ova deposited by insects floating in the atmosphere, and that they might possibly be hatched by the electric action. I next imagined, as others have done, that they might have originated from the water, and consequently made a close examination of several hundred vessels filled with the same water as that which held in solution the silicate of potassa. In none of these vessels could I perceive the trace of an insect of that description. I likewise closely examined the crevices and most dusty parts of the room with no better success."

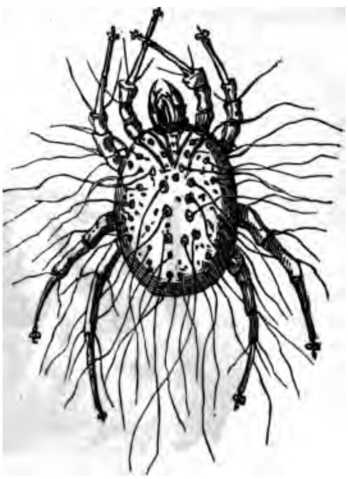


fig. 272.

This same hitherto unobserved acarus has been produced in electrified solutions of nitrate and sulphate of copper, of sulphate of iron, sulphate of zinc, fluo-silicic acid, and in ferrocyanuret of potassium. Mr. Weeks, the indefatigable experimenter at Sandwich, took every means to free the apparatus of all foreign matter, and to exclude the air, and after the action of a year the same insects were produced. Nevertheless, to the reflecting mind it cannot admit of a doubt that these insects must have been conveyed there by the wind or some other agent; as it is impossible to believe that voltaism or electricity can *create a new being.*

The science of voltaism is yet young; its mysteries are like many others, not yet known; facts are being daily added, and hence, as knowledge increases, truth will ultimately result.

The effect of voltaic action on the human system is much the same as that of common electricity; but when the battery is strong, an aching sensation is produced, and pain wherever there is a wound in the direction of the current. To receive a shock, the skin has generally to be moistened, as the intensity of voltaic electricity is weak, and requires conductors; thus it is usual to wash the hands in salt and water, or to hold a piece of metal in each, before making the connexion; or to have two basins of water, wherein the ends of the wires are placed.

Space will not allow us to do justice to the numerous *savans* who have been engaged in the investigation of animal electricity. We may, however, refer to a work recently published on this subject by Mr. Smee; and extract from his book one of the earliest of his numerous recorded experiments. Having obtained the arrangements necessary for measuring feeble currents of electricity, he applied his test to the living animal in the following manner: The animal, represented in fig. 273, was a rabbit, into

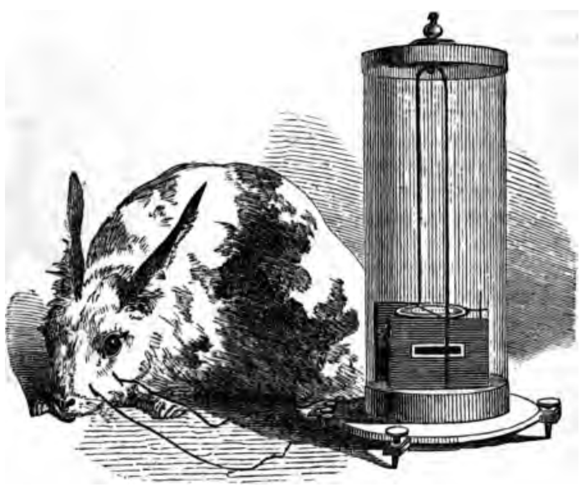


fig. 273.

the cheek muscle of which he introduced a sewing-needle, whilst a second needle was placed in the cellular tissue beneath the skin. "After leaving them for a few minutes, so that they might be in the same state, they were connected with the galvanometer, without sensible deflexion of the

needle. After a few moments more, the animal, not liking its treatment, made an attempt to bite; the mechanism of volition was instantly exhibited by the deflexion of the galvanometer. A piece of wood was then given to the animal to bite, upon which it used all its powers of mastication; and, by catching the oscillation of the needle, a very powerful electric current was exhibited. In this experiment the deflexion of the needle proved the existence of a voltaic current during the action of biting, and thus denoted the mechanism of the force employed to throw the muscles into operation."

Our illustration, fig. 274, represents the arrangement of an experiment

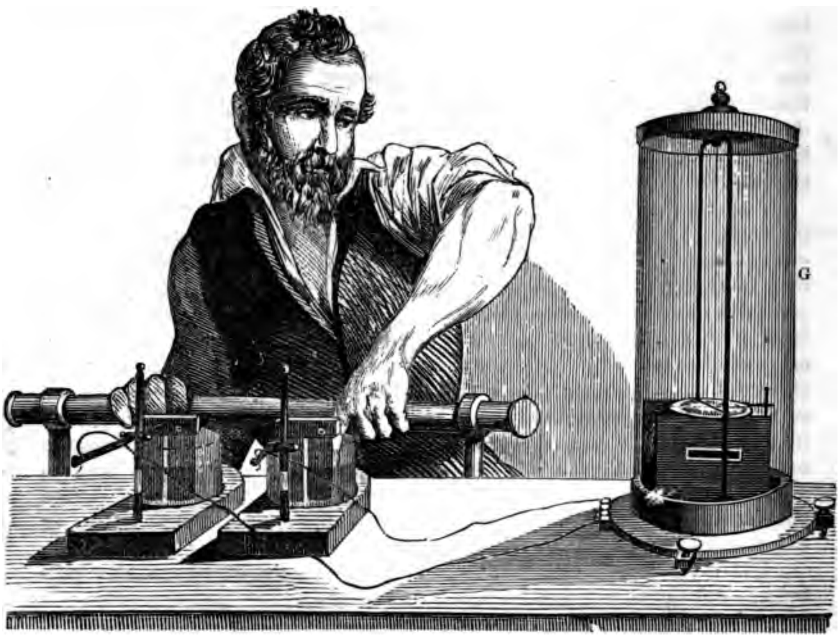


Fig. 274.

recently performed by M. Dubois-Reymond, a gentleman eminent in the study of "organic electricity." A cylinder of wood is fixed firmly against the edge of a table; two vessels filled with salt and water are placed on the table, in such a position that a person grasping the cylinder may at the same time insert the fore-finger of each hand into the water. Each vessel contains a metallic plate, and communicates by two wires with an extremely sensitive galvanometer G. In the instrument employed by M. Dubois-Reymond, the wire made 24,000 turns. The apparatus being thus arranged, the experimenter grasps the cylinder of wood firmly with both hands, at the same time dipping the fore-finger of each hand in the saline water. The needle of the galvanometer remains undisturbed; the electric currents passing by the nerves of each arm, and being of the same force, neutralise each other. Now if the experimenter grasp with energy the cylinder of wood with the right hand, the left hand remaining flaccid and free, immediately the needle will move from the west to the south, and describe an angle of 30°, 40°, and even 50°; on relaxing the grasp, the

needle will return to its original position. The experiment may be reversed by employing the left arm, and leaving the right arm free; the needle will in this case be deflected from the west to the north. This reversing the action of the needle, by the contraction of the muscles of the right and left arm alternately, places beyond all doubt the question of the electric current being induced through the agency of the nervous system.

Three conditions are necessary for the success of this experiment: 1. Great muscular force; 2. The precaution to contract the muscles of only one arm at the same time; 3. That the skin of the hand should be soft, quite clean, and free from any kind of wound, however small.

If the experimenter is too feeble, the needle is scarcely disturbed. If both arms are contracted unequally at the same time, the deflection only shews the excess of force of one arm as compared with the other. When the skin of the hand is thick and hardened, it is a bad conductor of electricity, and the least scratch or wound gives rise to chemical actions which develope of themselves the electric currents. The incontestable result of this experiment is, that the human will, producing a muscular contraction, causes a deflection of the needle.

The theory which accords best with the numerous experiments is the following: The nerves are the channels or seats of continuous currents of electricity, which contraction of the muscles, pain, and other circumstances may interrupt. At the moment the fingers are plunged into the saline water, the needle remains perfectly quiet; the currents passing through both arms and in opposite directions neutralise each other. When one arm only is contracted, the electric current is interrupted in this arm; the current from the other arm, acting alone, causes the needle to deflect according to the muscular or electric force developed. The nervous phenomena have, then, a close analogy with those of electricity. Future research and discovery may some day inform us if the will by which the muscles are contracted is not itself induced by electricity, of which the nerves are the source or channels, impressed and acted upon by external causes or impressions.

The experiments on dead animals are curious, but horrible to the spectator. For instance, when the wires from a battery are applied to the neck part of the head of an ox recently killed, by bringing in contact the nerve and muscle, the eyes are opened, the nostrils distended, and the action of eating takes place as if life was restored with all its functions to the dead head. Pain the most intense appears in the countenance, from the rolling and distended eye-balls, and the labour of the nostrils. Dr. Ure, in presence of several medical men, experimented on a criminal who had suffered death by hanging. The blood having first been allowed to escape from the body, a rod from the battery was placed in contact with the spinal marrow at the neck, and the rod from the other end of the battery brought in contact with the sciatic nerve at the hip, when the whole body was convulsed as if shuddering from cold. The knee was bent, and an incision being made in the heel, one of the rods was moved to that part, when the leg was thrown out with such force as to nearly throw down the assistant, whose whole strength could not prevent its action. In these experiments the nerves were always touched by the positive wire, and the muscles by the negative; in a reverse application the motion would have been feeble.

Dr. Wilson Philip proved that when he severed the eighth pair of nerves in rabbits, the food in their stomachs remained undigested, and they died

of suffocation. But after dividing the nerves, and distributing the galvanic power below the severed nerve to a disc of silver opposite the stomach, the operation of breathing and digestion proceeded as usual. The doctor also found he could continue the motion of the heart and circulation after the brain and spinal marrow of a rabbit were removed; and concludes his investigations by saying, "hence galvanism seems capable of performing all the functions of the nervous influence in the animal economy; but obviously, it cannot excite the functions of animal life, unless when acting on parts endowed with the living principle."

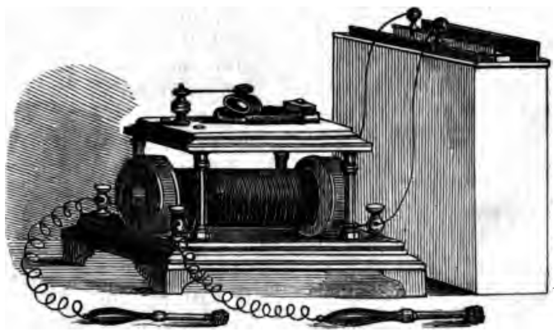


fig. 275. Electro-magnetic Coil Machine.

The *Electro-magnetic Coil Machine* is now most extensively used as a remedial agent in the treatment of many forms of disease of the human body; decided relief has been obtained and cures effected in *paralysis, lockjaw, St. Vitus's dance, tic doloreux, deafness*, and various other cases. A weak current must in all be begun with, and gradually increased in strength as the patient ceases to be affected by it; the best form for administering the galvanism is by the agency of such a machine as is here represented, fig. 275. From *the battery*, an upright jar in which plates of zinc are immersed in diluted sulphuric acid, proceed two copper wires, which are connected by two binding screws to the magnetic coil. This is made by winding round a hollow cylinder of wood a considerable length of stout copper wire, covered with cotton thread for the purpose of insulation; over this coil a much greater length of fine copper wire, previously covered with cotton, is wound. The two ends of the wire are then firmly connected with the two binding screws in front of the apparatus. The coil of thick wire is called the *primary*; through it the current from the battery first circulates. The coil of thin wire, termed the *secondary*, is intended to convey to the patient the electricity which is developed in it by induction every time contact between the primary coil and battery is broken and renewed. The breaking and renewing of the battery contact is effected by a little electro-magnet, with a vibrating armature, placed on the top of the small stage, through which the current from the battery is caused to pass at very short intervals. The vibrating motion of the armature throws on and cuts off the electric current from the coil, and a rapid series of shocks may thus be communicated to a patient, being directed through any part of his body by means of the sponge directors shewn lying loose in the figure.

By one of those singular coincidences in the history of discoveries, when the minds of scientific men are directed to a subject, did Jacobi of St. Petersburg in 1837, and Spencer of Liverpool in 1838, announce what the former called Galvano-plastik, and the latter Electrography. Although there existed this difference of time, still the discoveries were independent of each other. The art is now named electro-metallurgy, of which electro-plating is an important branch. Mr. Spencer's invention was for depositing copper on metallic surfaces, using a slight coating of wax. M. Jacobi, in March 1840, recommended the giving, by means of plumbago, a conducting surface to non-metallic substances, thus opening out an extensive field for its exercise: but in January of the same year, Mr. Murray described the same mode in this country, and deservedly received the silver medal from the Society of Arts for his invaluable discovery.

The practice of electrotyping from this period took its rise: it is the delight of those amateurs who have leisure for its practice, and has become a most important branch of the industrial arts of this and other countries. The principle is simple, and may thus be explained: A piece of zinc and a piece of copper being attached, the one to one end of a wire and the other to the other end, then placed in a basin of water containing sulphuric acid, the water is decomposed; the hydrogen escaping at the copper surface, and the oxygen combining with the zinc. But if a solution of sulphate of copper be substituted for the diluted sulphuric acid, the hydrogen then liberates the copper from its solution, by combining with the oxygen previously united with it, and the metal is deposited on the copper plate.

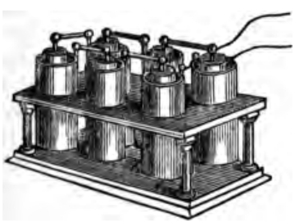


fig. 276.

For the purpose of electrotyping, it is requisite to have a continued current of voltaic electricity, as nearly as possible of the same strength. Daniell's "constant" battery has been found well adapted to supply such a current for operating on a small scale. It consists of a cylinder of copper, having in the inside a cylindrical vessel of biscuit-ware, made of porous earth, unglazed and very thin; and in the middle of this is a solid rod of zinc, having a support at the top, by which it rests on the middle cylinder. Around the copper cylinder is a perforated shelf, on which are laid crystals of sulphate of copper. This keeps up a constant supply of sulphate of copper in the water. In the inside cylinder there are poured ten parts of water to one of sulphuric acid. By joining together a number of these single batteries one of any extent of power may be formed, as in fig. 276. In some electrotyping, arrangements of the moulds are placed in single batteries, and there acted upon. In others, there are vessels in which the objects are placed, and a connection made by the wires from the battery.

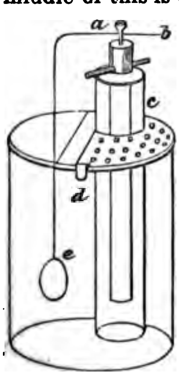


fig. 277.

A single-cell apparatus for electrotyping purposes is represented in the diagram 277, *e* being the mould or object from which it is desired to have a metal fac-simile, *a* a rod of amalgamated zinc, *b* the wire joining them;

c the porous earthenware containing the solution of acid and water, *d* the copper solution. The solution is first poured in, then the acid-water; and finally the wire, with the mould hanging at one end, is attached to the zinc. There is particular care to be taken that the shelf is kept supplied with crystals of sulphate of copper, that the quantity be not too small proportionately to the zinc, and that the concentrated part of the solution be not allowed to remain at the bottom.

Fig. 278 is another arrangement: *a* is the battery; *b* the decomposition cell filled with the solution of sulphate of copper; *e, f* sheets of copper to furnish a supply to the moulds. In this cell the solutions are poured in,

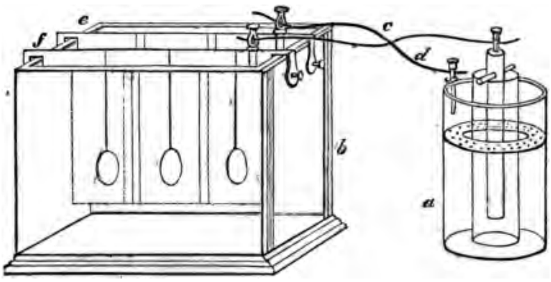


fig. 278.

the wire *d* connecting the copper sheet and the copper of the battery, after which the wire *c* from the zinc to the moulds is fixed, and adjusted in its proper position. The charging liquid is a mixture of one part sulphuric acid, two parts saturated solution of sulphate of copper, and eight parts of water. In this arrangement, when the wires are connected, the copper from the solution is deposited on the mould, and the plate of copper dissolved, which sustains the strength of the solution. Rather a longer time is required by this method than with the single cell; but two days will produce a medal of very good substance, firm and pliable; the time required, however, for these experiments, depends much on the temperature. If the solutions are kept boiling, a medal may be made in a few hours: in severe weather, the action of the battery almost ceases, and it is necessary to carry on the operations before a good fire.

There are several other arrangements of batteries sold by philosophical-instrument makers, suitable to the various purposes for which they are required.

Electro-plating and gilding are accomplished by having very carefully prepared solutions of the desired metals first made, either for a single-cell battery or a decomposing trough.

The purposes to which electro-metallurgy is being applied are innumerable. By it are articles silvered, coppered, zinced, and gilt; etching is effected, and casts from metal type, wood-engravings, busts and statues; pipes are made without joints, and metal lace and cloth prepared; delicate flowers and minute insects with life-like exactness modelled.

If a galvanic battery heat a wire of a given size and length, and the wire be drawn out to a greater length, it will also equally heat it in its extended state; or, as Faraday states, "a current that will heat one inch of platinum will heat a hundred inches, allowance being made, however, for

the cooling effects of the air." This fact gave rise, at the suggestion of Mr. Palmer, to its being employed in submarine operations by Lieut.-General Pasley; first in the removal of obstructions in the Thames, and afterwards to the wreck of the Royal George at Spithead. But perhaps one of the most interesting works of magnitude effected by this power was at the blasting of the Round Down Cliff at Dover, on Thursday, January 26th, 1843. We give the following graphic account, from the *Illustrated London News*, of this extraordinary example of engineering skill.

"A small arched drift-way or tunnel, 300 feet in length, running from east to west, was pierced through the bottom of the cliff; from this, at nearly equal distances, three well-like shafts were sunk, and from these again proceeded three horizontal galleries. At the end of each gallery a chamber was prepared, with a box for the gunpowder. The centre box contained 75 barrels, and the eastern and western 55 each, making in the whole the unparalleled charge of 185 barrels, or 18,500lbs. The gunpowder was placed in upright bags, the mouths open, and powder sprinkled very thickly between them. Two bursting charges were placed in each box, by which ignition in two places in each charge was produced at the same instant, and the simultaneous action of the whole charge very much facilitated. These charges were placed 70 feet from each other; the centre one (the point of greatest resistance) 90 feet, and the lateral ones 70 feet from the face of the cliff. The apparently dangerous work of packing the powder and inserting the firing-wires in the bursting-charges was completed in three hours, by Mr. Hodges, the assistant-engineer, and Corporal Rae, of her Majesty's Sappers and Miners. The chambers and contents were then carefully examined and approved by General Pasley and Lieut.

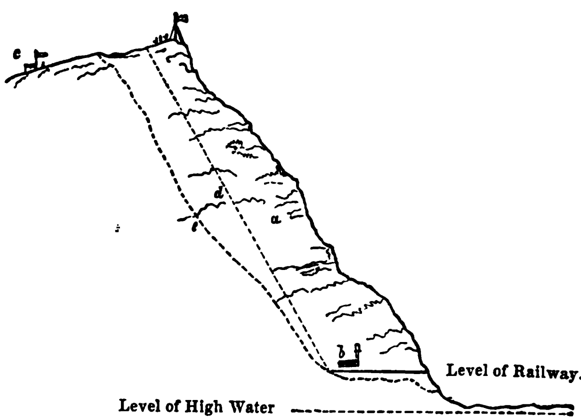


fig. 279. *a.* Section of Round Down Cliff. *b.* Drift-way, and chamber where the powder was placed. *c.* Battery-house. *d.* Line of required face. *e.* Face formed by the blast. Scale, 200 feet to an inch.

Hutchinson, and the galleries and shaft closed up with tightly rammed chalk and sand. The mass to be scattered by this latent power was calculated at about 500,000 tons; but the quantity actually removed was proved to be upwards of 1,000,000 tons.

On the slope of the cliff a wooden shed was constructed, in which was

placed a triple set of immense compound batteries, each one consisting of three sets of Daniell's batteries of six cylinders each, and two plate batteries of twenty plates each. From each of these batteries a wire was conducted over the cliff to a powder-chamber, where it terminated in a

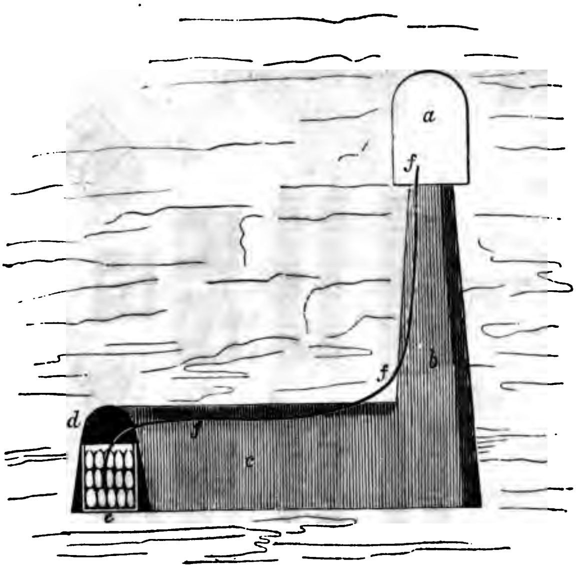


fig. 280. *a*. Drift-way. *b*. Shaft. *c*. Gallery. *d*. Powder-chamber *e*. Box of powder-bags. *fff*. Wire from batteries. Scale, 10 feet to an inch.

bifurcated point of platina, which the galvanic fluid, as it passed over them, heated to an intense white heat, to ignite the powder. These wires were composed and formed of stout copper wires placed round a rope, to which they were firmly attached by a coil of spun-yarn, and the whole again wound round and covered by well-tarred yarn. These wires were about 2200 feet in length. Five large charcoal fires, to dissipate damp, completed the arrangements."

"At precisely twenty-six minutes past two o'clock a dull, muffled, booming sound was heard, accompanied for a moment by a heavy jolting movement of the earth which caused the knees to smite. The mines were fired! In an instant the bottom of the cliff appeared to dissolve, and to form by its melting elements a hurried sea-borne stream. The superincumbent mass, to the extent of 500 feet, was then observed to separate from the mainland, and as the dissolution of its base was accomplished, to sink, by gradual subsidence, to the beach. In two minutes its descent and dispersion were accomplished. The huge volleys of ejected chalk, as they swelled the lava-like stream, seem to roll inwards upon themselves, crushing their integral blocks, and then to return to the surface in smaller and coalescing forms. The mass seemed to ferment—to be splitting, whirling, fleeing, under the influence of an unseen but uncontrollable power. There was no roaring explosion, no bursting out of fire, and, what is very remarkable, not a single wreath of smoke, for a mighty

agent had done its work under an amount of pressure which almost matched its energies; the pent-up fires were held in their intensity till all smoke was consumed, and when their "dogs of war" were actually let loose, they were even then compelled to "do their spiriting gently." A million tons of weight and a million tons of cohesion held the reins. When the turf at the top of the cliff had been launched to the level of the beach, the stream of *débris* had extended a distance of 1200 feet, and covered a surface of more than fifteen acres!"

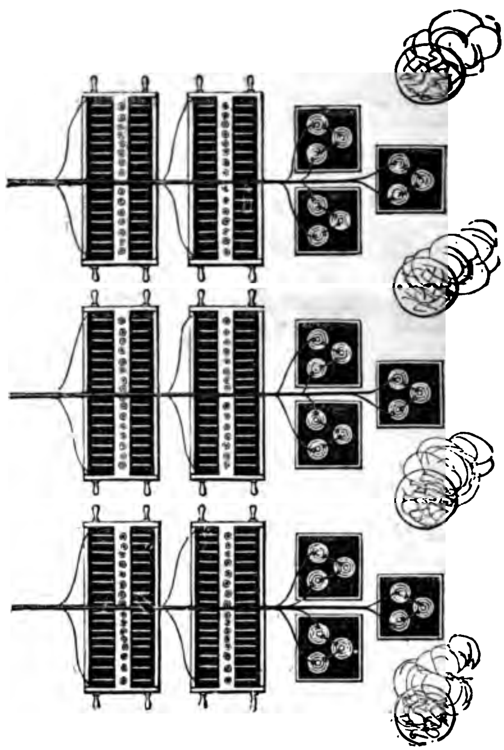


fig. 281. Plan of the Batteries.

Sir Humphry Davy exemplified the intense heat to be derived from the voltaic battery. With a series of 2000 four-inch plates, he produced an arched stream of light between two charcoal points, with which he fused the most unmanageable of the metals with the utmost ease. Diamond vanished into carbonic acid gas; when thin leaves of gold were burned, a beautiful white light tinged with blue was emitted; silver leaf gave an emerald-green light, copper a bluish-white light with red sparks, lead a purple, zinc white tinged with red. Professor Daniell, with his improved battery, produced such a powerful flame between charcoal points, as to scorch his own face and inflame the eyes of the spectators. The cause of this light science has not yet been able to determine; all that is known

is, that its properties are the same as those of the sun's rays, and have been therefore substituted by the daguerreotypist. Some years ago M. Archereau

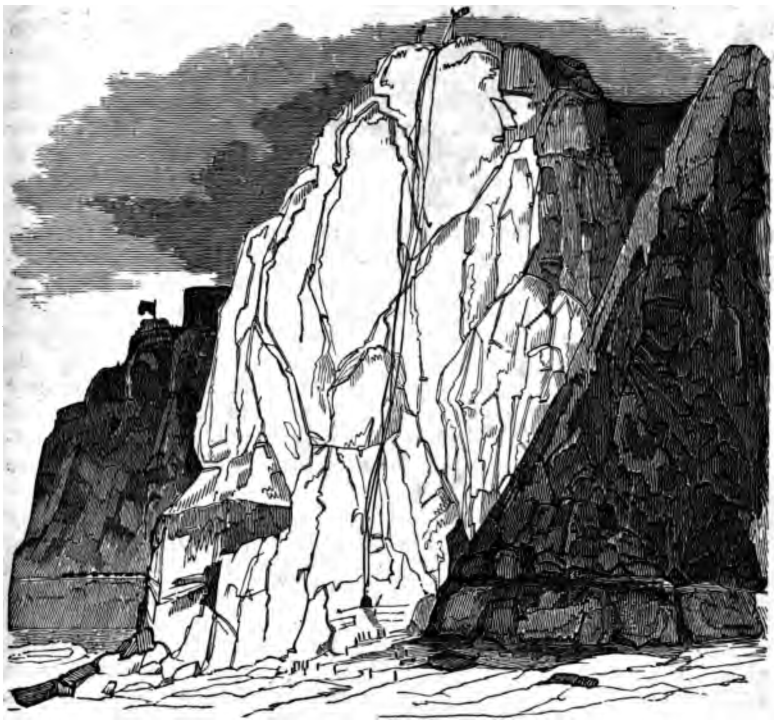


fig. 282. Round Down Cliff from the Beach as it appeared after the explosion.

exhibited the electric light in Paris, and it was proposed to have it in several points, whereby the city might be illuminated as if by a sun at night. Difficulties however existed, which many ingenious minds have for some time been endeavouring to obviate, arising principally from the inability to render the light continuous. Mr. Allman proposed an ingenious self-adjustment, whereby when the electricity was more than necessary, the charcoal points became wider apart, and when it decreased they approached nearer.

In 1846, Messrs. Greener and Staite took out a patent for this mode of illuminating thoroughfares and public buildings. They proposed to use charcoal and platinum points in air-tight vessels lighted by galvanism. Mr. Staite, in a lecture, said, With a battery of 40 small cells in series, the light was equal to 380 tallow candles, 300 wax candles, or 64 cubic feet of gas; this being effected by the consumption of little more than three-quarters of a pound of zinc per hour. In 1848 it was publicly exhibited in London.

Mr. J. W. Watson has succeeded in producing the electric light at

a smaller cost than any previous inventor. The great economy of his patent process consists in making the battery available for other chemical purposes; viz. that of forming valuable pigments for use in the arts.

In all galvanic batteries at present employed, nothing but electricity was gained on the profit side—all else was loss. The products were, commercially speaking, worthless. Generally, electricians contented themselves with using the common mineral acids and the metals in use since Volta's discovery; but Mr. Watson has sought to introduce some of the rarer metals, the products of the decomposition of which would cover their expense. In those experiments, however, he was not rewarded with the desired success, and had therefore turned his attention to the discovery of new exciting agents, or electrolytes; and in this he was satisfied that if he had not accomplished all, he had at least made such progress towards improvement as would materially benefit the commercial world. Electrical illumination was now possible, and it was to be hoped that before long the splendid light afforded by the voltaic battery would be ranked among the common things of life. The batteries were termed, from the nature of their products, the chromatic batteries. It might appear difficult to those unacquainted with chemistry, how any number of galvanic arrangements could be made to produce a variety of colours. But the real number of natural colours was small, and the difference of a single shade imparted to each a distinct commercial existence as a colour.

By the use of a few substances introduced into five batteries, they were able to produce no less than 100 valuable pigments, transcending by an immense percentage the original value of the articles from which they were produced. The colours are formed, not by any subsequent mixing of the products of the batteries, but are the result of the actual development of the electricity in the battery; and the materials employed aided the galvanic effect by giving "constancy" to the machine, a result of the most vital importance. The manner of working the battery is shortly this:

The cast-iron and zinc battery (invented by the Rev. N. J. Callan, of Maynooth, and commonly called the Maynooth battery), when worked by sulphuric acid, produced sulphate of iron and sulphate of zinc, which were comparatively worthless, or at least in no way equal to the cost of sulphuric acid. But the working of this battery was rendered not only economical but profitable, by adding to the iron and zinc cells prussiate of potash, which, when combined with the sulphate of iron, produced a splendid blue pigment of very great value—prussian-blue; and that of a quality and colour far superior to any in the market. A second colour, closely vieing with ultramarine, was also produced by the same process. In another battery, of platinised lead and zinc, also invented by the discoverer of the Maynooth battery, chrome-yellow pigments were produced by adding bichromate of potash in the same manner as with the prussiate of potash. The tint of these pigments, which constitutes their value in the market, are varied by the proportion of the salts added. By combining the salts in a battery of iron and zinc—the prussiate of potash to the iron and the chromate of potash to the zinc—a green colour was produced of a depth of tint dependent on the quantity of the two normal colours forming the compound. In like manner, by adding prussiate of

potash to the lead battery a white pigment is produced, of great body, and perfectly free from the fault of blackening by exposure to sulphuretted hydrogen. If chromate of potash alone were added to the iron battery, a deep brown colour is produced; and lastly, if lime were added with chromate of potash to the lead battery, a red pigment is formed of great brilliancy and body.

During the working of the batteries, the hydrogen which escapes from the zinc cells is profitably employed for the manufacture of acetic ether and ammonia. The various pigments, when removed from the batteries, of course carry with them a large quantity of spent acid solution, which is also employed for the manufacture of nitrate of iron, white lead, and plaster of Paris. All the pigments which have been produced by electricity, the colour-trade have readily purchased; while the uniformity of the heat produced by the action of the batteries rendered the production of the most delicate shades a matter of certainty. The preparation of the colours for the market consists in nothing more than washing and drying.

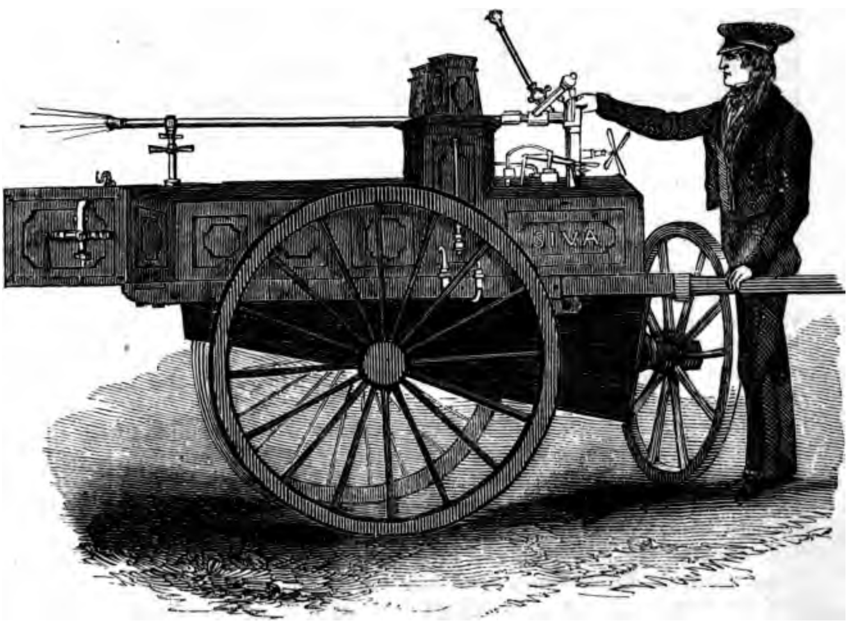


fig. 283. The Electro-Galvanic Gun.

A very ingeniously constructed gun, fired off by the agency of a galvanic battery concealed within itself, was exhibited in London, which discharged balls five-eighths of an inch in diameter at the rate of 1000 per minute.

In connexion with the subject of galvanic batteries, are the beautiful metallo-chromes. Mr. Gassiot's process is to place a plate of highly polished steel in a glass basin containing a clear solution of acetate of lead, and

over it a piece of card with some regular device cut out, as seen in the diagram. A small rim of wood should be placed over the card, and on that a circular copper disc. On contact being made from 5° to 20° with two or three cells of a small constant battery, the steel plate being con-

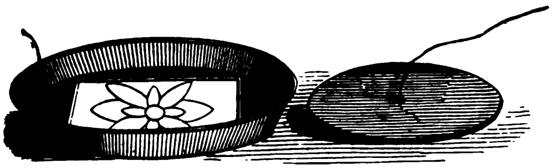


fig. 284.

nected with the copper or silver, and the copper disc with the zinc, the deposit will be effected, and a series of exquisite colours will appear on the steel plate. These colours are films of lead in a high state of oxidation, thrown down on the surface of the steel, and the varied tints are occasioned by the varied thicknesses of the film, the light being reflected through them from the polished steel underneath. By placing the plate before a window and inclining a sheet of paper at 45° over it, the reflected light shews all the prismatic colours; by transmitting light a series of prismatic colours complementary to the first series appear in the place of the former.

MAGNETISM.

Man has detected another mysterious power in nature, similar to that of electricity and galvanism, which he has enlisted in his service, and rendered subservient to his purposes.

A mineral or ferruginous stone, found commonly in iron mines, of various forms, sizes, and colours, endowed with the property of attracting iron, of pointing itself in a certain direction, and of communicating the same property to iron and steel bars; it was called the *Loadstone, Leading-stone,* or magnet.

Plato and Aristotle state that the ancients were acquainted with the attractive and repulsive powers of the magnet; but no mention is made of its directive property, which is of all others the most useful and interesting. Even of this we have it on record that, many centuries before the Christian era, the Chinese, when in a battle, being overtaken by a dense fog, directed the movements of their troops by means of a magnet; to them, then, its *directive properties* must have been familiar. Still its uses and application to the purposes of navigation is only of comparatively modern date in other parts of this world. It is mentioned by old continental writers in MSS. of the twelfth century; and Cardinal Vetri in his History of Jerusalem, about the date of 1200, names the magnetic needle and its importance to sea-faring persons. Dr. Gilbert says the compass was brought from China to Italy in 1260, by Paulus Venetus. That its uses were known in this country half a century after this date is apparent, for when Robert Bruce, in 1307, sailed from the protection of Christiana of the Isles, and landed at Carrick, Barbour, who wrote an account of the voyage in rhyme, states they steered by a fire-light to shore,

"For they na needle had, nor stane."

From what may be gleaned on the subject in ancient records, it would seem that the direction of the needle was known about the commencement of the fourteenth century. But that this direction was subject to change was not a fact yet developed when Columbus first ventured to seek the shores of a new world, will appear from the following extract from Washington Irving's Life and Voyages of Columbus: "On the 13th of September, 1492, he perceived about night-fall that the needle, instead of pointing to the north star, varied but half a point, or between five and six degrees to the north-west, and still more on the following morning. Struck with this circumstance, he observed it attentively for three days, and found that the variation increased as he advanced. He at first made no mention of this phenomenon, knowing how ready his people were to take alarm; but it soon attracted the attention of the pilots, and filled them with consternation. It seemed as if the laws of nature were changing as they advanced, and that they were entering into another world, subject to unknown influences. They apprehended that the compass was about to lose its mysterious virtues; and without this guide, what was to become of them in a vast and trackless ocean? Columbus tasked his science and ingenuity for reasons with which to allay their terrors. He told them that the direction of the needle was not to the polar star, which, like the other heavenly bodies, had its changes and revolutions, and every day described a circle round the pole, but to some fixed and invisible point; and therefore the variation was not caused by any failing in the compass. The high opinion that the pilots entertained of Columbus as a profound astronomer, gave weight to his theory, and their alarm subsided."

That iron became from certain circumstances endowed with the power of the magnet was first observed in 1590 by a surgeon of Rimini; and in 1600, Dr. Gilbert of Colchester wrote a work on magnetic bodies, and termed the extremities of the needle *poles*. Dr. Halley, in 1683, wrote on the theory of the science and suggested the situation of the magnetic poles, of which he believed there to be four, and likewise offered suppositions for the change in the direction. Mr. Graham, a London mathematical instrument maker, in 1722 noted most carefully the daily variation, and found that seasons as well as hours made a difference. Although the making of artificial magnets was long known, still they were weak in power until the discovery of a better mode was contrived by Dr. Knight, about 100 years ago, and several distinguished men afterwards improved upon his method. To A. C. De Coulomb we owe the great discovery that magnetic power, like electricity, resides on the surfaces of iron bodies, and does not penetrate into the interior of solid bodies. He also was the first who invented the method of measuring the quantity of action in electricity, and from it deduced the fact of electrical attractions and repulsions following the Newtonian law. The instrument he invented by which he arrived at these conclusions was the Torsion-balance, a needle hanging from a silk fibre in which the force of torsion or turning necessary to produce a given effect serves to measure the amount of attraction. Coulomb's torsion-balance when fitted up for electrical purposes consists of a horizontal needle *c*, made of shell-lac, having a gilded pith ball at one

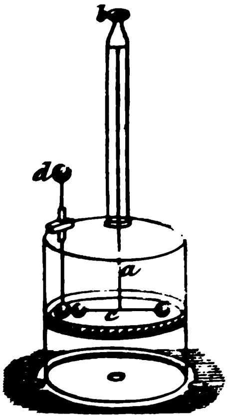


fig. 235.

end, and a counterpoise at the other; this is suspended by a silk thread or spun glass *a* attached to the screw *b*, and can be twisted round its axis. At the zero point of the graduated scale, a copper wire *d* with a ball enters through the glass cylinder, this wire is also provided with a pith ball, gilded, and of the same size as the other; both balls touch when the torsion needle is in a state of equilibrium, or they may be brought into contact by turning the screw *b*. The scale is marked on the circumference of the glass. Philosophers and philosophy owe a deep debt of gratitude to this founder of experimental physics in France for this instrument. Coulomb added much to our knowledge on the manufacture of artificial magnets, and in 1802 announced that all bodies are subject to magnetic influence, which he suspected to be caused by portions of iron diffused in them. To test this he performed a most delicate experiment, which we will endeavour to explain. With the utmost pains he purified a piece of silver by cupellation, and then formed with it a needle; with another piece of silver he mixed 1-320th part of iron, and made it likewise in the form of a needle. He then subjected them to the influence of a magnet, and found that the pure silver needle was affected 415 times less than the iron and silver one, therefore he inferred there was 415 times less iron in the pure silver one than in the other. Now as the mixed needle had 1-320th part of its weight of iron in it, the silver one must have 1-415th part of that quantity of iron, as it was so much less influenced by the magnet; it would therefore according to this calculation contain 132,799 parts of pure silver and one of iron; which is a quantity so small that no other test could possibly determine.

Professor Barlow, of the Royal Military Academy at Woolwich, while investigating the effect of the iron in a man-of-war on the compass, discovered amongst other things which he explained, that there is a great circle around every mass of iron, inclined to the horizon at an angle equal to the complement of the dip of the needle; he then proceeded to shew how to reckon the deviation. He found that a hollow iron shell acted as powerfully as a solid one at the same distance; therefore, a plate of about five pounds weight would represent and counteract the attraction of all the other iron in the ship. This was tested in all parts of the world, and found to be a fact of so much value that the government board gave the worthy and ingenious professor the utmost reward in its power, 500*l.*; and the Emperor of Russia sent him a valuable watch and appendages, as a testimony of his appreciation of the importance of the invention. Captain Parry, on this subject, says, "such an invention as this, so sound in principle, so easy in application, and so universally beneficial in practice, needs no testimony of mine to establish its merits; but when I consider the many anxious days and sleepless nights which the uselessness of the compass in these seas had formerly occasioned me, I really should have esteemed it a kind of ingratitude to Mr. Barlow, as well as great injustice to so memorable a discovery, not to have stated my opinion of its merits,

under circumstances so well calculated to put them to a satisfactory trial."

Dr. Dalton, Professor Hanstein, M. Arago, Captain Back, and others have made many observations on the great derangement of the needle which arises on the appearance of the aurora borealis, which is always in the direction of the magnetic pole. Although the Northern Lights are rarely seen farther south than Scotland, yet they disturb the magnetic needle at Paris. Faraday has discovered that all metals are magnetic, but that each requires a certain temperature for development.

The loadstone as found in its native state consists of two oxides of iron, with a small quantity of quartz and alumina. It is principally obtained from Arabia, China, Siam, Norway, and Sweden; and sometimes a little has been found among the iron ore of England. Small loadstones are more energetic than large ones. Sir Isaac Newton had one in his ring that lifted two hundred and fifty times its own weight.

The laws of magnetism are certain results, which from numerous and accurate experiments are found to obtain in all natural and artificial magnets: the principal of which are—the *Poles of the Magnet*, those points which seem to possess the greatest power, or in which all the virtue appears to be concentrated.

The *Axis of a Magnet* is a right line which passes from one pole to another.

The *Equator of a Magnet* is a line perpendicular to the axis, and exactly between the poles.

The *Magnetic Meridian* is a vertical circle in the heavens, which intersects the horizon in the points to which the magnetic needle directs itself when at rest.

The characteristic properties of the magnet are—its attractive and repulsive power; its directive power; its dip or inclination to a point above or below the horizon; its power of communicating its own properties to certain other bodies.

The phenomena of the magnet are very numerous; a few of the principal are—a magnet, when freely supported either by a thread or in a light vessel on water, will place itself in a direction nearly coincident with the poles of the earth.

This direction of the magnetic needle is not the same in all parts of the world, nor in the same place at different times.

A needle which is not magnetised, being exactly balanced, will, if touched by a magnet, so as to communicate that property to it, have its equilibrium destroyed, one of its extremities dipping considerably below the horizontal plane.

The centres of action of a magnet are at a very small distance from its extremities. In every magnet there are two poles, of which the one points northwards, the other southwards; and if the magnet be divided into any number of pieces, the two poles will be found in each piece. The poles of a magnet may be found by holding a very fine short needle over it, for where the poles are, the needle will stand upright, but nowhere else. The magnetic force, as it passes out, may be shewn by strewing about the poles of the stone, on every side, some iron or steel filings on a sheet of white paper; these small particles will be affected, and so disposed as to shew the course and direction of the magnetic particles in every part.

Thus in the middle of each pole it appears to go nearly straight on; towards the sides it proceeds in lines more and more curved, till at last the curve-lines from both poles, exactly meeting and coinciding, form numberless curves on each side, nearly of a circular form. A few gentle knocks on the table will be necessary to dispose properly those particles which lie at a distance.

These poles, in different parts of the earth, are also differently inclined towards a point under the horizon; and though contrary to each other, help mutually towards the magnet's attraction and suspension of iron.

If two magnets be spherical, one will turn or conform itself to the other, as either of them would do to the earth; and after they have so conformed, they have a tendency to approach or join each other; but if placed in a contrary position they repulse each other.

If a magnet be cut through the axis, the segments or parts which before were joined will now repel each other. If the magnet be cut perpendicular to its axis, the two points which were before conjoined will become contrary poles; one in the one, and one in the other segment. Iron receives virtue from the magnet by application to it, or barely from an approach towards it, though it do not touch it; and the iron receives its virtue variously, according to the part it is made to touch.

If an oblong piece of iron, it receives its virtue only in its lengthways. A needle turns its end the same way, that is, towards the poles of the earth, as the magnet itself does.

A magnet will take up much more iron when *armed* than it can alone; and in north latitudes the south pole of a magnet will raise up more iron than its north pole.

The power or virtue of a magnet may be impaired by lying long in a wrong position; also by rust, wet, &c., and may be quite destroyed by fire, lightning, &c.

A wire or bar being touched from end to end with one pole of a magnet, the end at which you begin will always turn contrary to the pole that touched it, and if it be again touched the same way with the other pole, it will then turn the contrary way; or if it be touched only in the middle, without moving either backwards or forwards, in the place touched will the pole be, and the two ends the other pole.

If a magnet be heated red hot, and again cooled, either with its south pole towards the north, in a horizontal position, or with its south pole downwards, in a perpendicular position, its pole will be changed. Hard iron tools, well tempered, when heated by brisk filing or turning, will attract thin iron or steel filings, and hence we observe that files, punches, &c., have a small degree of magnetic virtue. The iron bars of windows &c. which have stood a long time in an erect position grow permanently magnetic; the lower ends of such bars being the north pole, and the upper end the south pole. Tongs, pokers, &c. from being often heated, and set to cool again in an upright position, gain this magnetic property. Sometimes iron bars, by long standing in a perpendicular position, have acquired the magnetic virtue in a surprising degree.

A magnet acts with equal force in vacuo as in the open air.

A bar of hard tempered steel with the lower end inclined to the north, struck severely with a hammer, will become magnetic.

We remember a gentleman hanging up two pieces of rod-iron, one in

the direction of the magnetic dip, the other horizontal; after a lapse of three years they were examined, the one that had been hung in the direction of the dip snapped with great facility, the horizontally hung piece could be twisted into a knot. This is a subject that seems deserving of consideration in the erection of suspension bridges. Note, again, the accidents on railways; do not the greater amount of accidents on the lines lying east and west take place in the axles of the carriages and wheels, and those north and south from the rails snapping? we write without statistics to refer to; and would venture to suggest it as a subject worthy of future careful registration.

The mode of discovering when a piece of metal possesses magnetic properties is to bring it within the influence of a compass needle, when its north pole will attract the south pole, and repel the north pole of the needle if magnetic, and its south pole will attract the north and repel the south pole of the needle; thus, there is attraction and repulsion as in electricity.

It may be as well in this place to notice that magnetism differs from electricity in the fact that both polarities exist in the same body, and that one cannot exist without the other; while it may be remembered that one kind of electricity can be excited from one body and another from a different one. This polarity of the magnet is what renders it so serviceable to the purposes of navigation, mining, and travelling in unknown countries.

To illustrate the repulsion of magnetism, Cavallo fixed two pieces of iron wire to the ends of a piece of thread, and hung the thread at its centre over a hook; then he brought the north pole of a magnet a little below the wires, when the wires repelled each other to some distance. This made the ends of the wires near the magnet south magnetic poles, and the more distant ones north; but when the magnet passed a certain limit the south poles of the wire approached nearer to each other, at the

fig. 286.

same time the north poles diverged to a greater extent. This influence and action ceased instantly on removing the magnet.

Newton in his learned work, the *Principia*, considers magnetic force as being different from that of gravity. He says: "The magnetic attraction is not as the matter attracted; some bodies are attracted more by the magnet, others less; most bodies not at all. The power of magnetism in one and the same body may be increased and diminished, and is sometimes far stronger for the quantity of matter than the power of gravity, and in receding from the magnet decreases not in the duplicate, but almost in the triplicate proportion of the distance."

To construct the *Mariner's Compass* it is only necessary to take one of these magnetised needles, nicely balance and place it in a round box covered with glass, having a card or paper on which are marked 32 points; that is to say, the whole of the horizon divided into 32 parts. Every point is a 32d part of 360°, which is equal to $11\frac{1}{4}°$; a half point is equal to 5° 37′ 30″; and a quarter point equal to 2° 48′ 45″. North, East, South, and West, are termed the four *cardinal points*.

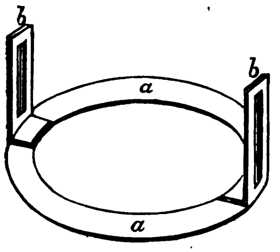


fig. 287.

On the edge of the box two pieces of brass, *b b*, are fixed upright in a circular ring *a a*, having oblong apertures cut in the centre termed sight-holes; a fine wire or hair is stretched down the centre of one of the upright pieces, the other having a fine slit only in it, then by applying the eye to one aperture until the wire or hair of the other passes over the object and the centre of the card, the angular distance or azimuth from the magnetic meridian is ascertained. It is then called the *azimuth compass*.

When the needle remains at rest that place is called the *magnetic meridian*. At Greenwich the magnetic meridian makes with the astronomical an angle of $23\frac{1}{2}°$ west. This variation from the direct north has been observed to be 23° 4′ 48″, to 23° 24′ 19″. It increases westward from 7 A.M. till about 1 P.M., about $7\frac{1}{4}'$ of arc; it then returns eastward till about 11 P.M., about $8\frac{1}{4}'$ of arc. This is called the *variation of the compass*, or *magnetic declination* west or east. The diurnal range in the summer of 1846 was 15′ 14″; in winter 11′ 53″; and for the year 13′ 34″; it was smallest in January and largest in September. Going from London and proceeding west on the Atlantic Ocean, the magnet is found to attain its greatest tendency towards the west; proceeding onwards it returns towards the north, and at the east of the United States of America it becomes due north, and further westward it becomes east. Going from London to the east, the western declination lessens, and at the eastern part of Russia it is due north; proceeding further east the variation becomes gradually more easterly.

If a piece of iron be balanced and afterwards magnetised, and placed on its former balancing point, it will be found to have lost its previous equilibrium, and the north point incline towards the earth about 70°. This is called the *dip*. Conveying this needle towards the north, the dip increases until it becomes vertical. Towards the south pole it dips to the south until it becomes vertical. The mean magnetic dip for 1846 at 21 hours at Greenwich was 68° 58′ ·6″, and at 3 hours 68° 57′ ·6″.

As the magnetic poles do not correspond with the poles of the earth, it is plain that the needle cannot point due north and south except in those countries where the magnetic and true meridian coincide, and it is this causes the variation of the needle. The south magnetic pole is believed to be somewhere about latitude 65° south, and longitude 130° west of London.

Of the discovery of the North Magnetic Pole, Commander Ross writes: "We reached the calculated place at eight in the morning of the 1st of June, 1831. I believe I must leave it to others to imagine the elation of mind with which we found ourselves now at length arrived at this great object of our ambition; it almost seemed as if we had accomplished every thing that we had come so far to see and to do; as if our voyage and all its labours were at an end, and that nothing now remained for us but to return and be happy for the rest of our days. . . . .

"The land at this place is very low near the coast, but it rises into ridges of fifty or sixty feet high about a mile inland. We could have wished that a place so important had possessed more of mark or note. It was scarcely censurable to regret that there was not a mountain to indicate a spot to which so much of interest must ever be attached; and I could even have pardoned any one amongst us who had been so romantic or absurd as to expect that the magnetic pole was an object as conspicuous and mysterious as the fabled mountain of Sinbad, that it was even a mountain of iron, or a magnet as large as Mont Blanc. But Nature had here erected no monument to denote the spot which she had chosen as the centre of one of her great and dark powers. . . . .

"The necessary observations were immediately commenced. . . . . The place of the observatory was as near to the magnetic pole as the limited means which I possessed enabled me to determine. The amount of the dip, as indicated by my dipping-needle, was 89° 59′, being thus within one minute of the vertical; while the proximity at least of this pole, if not its actual existence where we stood, was further confirmed by the action, or rather by the total inaction, of the several horizontal needles then in my possession. These were suspended in the most delicate manner possible, but there was not one which shewed the slightest effort to move from the position in which it was placed; a fact which even the most moderately informed readers must now know to be one which proves that the centre of attraction lies at a very small horizontal distance, if at any.

"As soon as I had satisfied my own mind on this subject, I made known to the party this gratifying result of all our joint labours; and it was then, that amidst mutual congratulations, we fixed the British flag on the spot, and took possession of the North Magnetic Pole and its adjoining territory in the name of Great Britain and King William IV. We had abundance of materials for building in the fragments of limestone that covered the beach; and we therefore erected a cairn of some magnitude, under which we buried a canister, containing a record of the interesting fact; only regretting that we had not the means of constructing a pyramid of more importance, and of strength sufficient to withstand the assaults of time and of the Esquimaux. Had it been a pyramid as large as that of the Cheops, I am not quite sure that it would have done more than satisfy our ambition, under the feelings of that exciting day. The latitude of this spot is 70° 5′ 17″, and its longitude 96° 44′ 45″ west."

Some time before this actual observation, Professor Barlow had distinctly marked the situation of the North Pole, and he remarks upon Commander Ross's observations: "the pole itself is precisely that point in my globe and chart in which, by supposing all the lines to meet, the several curves would best preserve their unity of character, both separately and conjointly, as a system."

The variation of the needle is subject to a gradual change; when first known, the variation as observed by Norman was 11° 15′ eastward; from 1657 to 1662, it pointed due north in London; it then began gradually going to the westward, and in 1815, according to Colonel Beaufoy, it reached its maximum, being 24° 27′ 18″ westerly, since which period it has been gradually decreasing. Thus it would appear that the magnetic poles are not stationary, but revolve round some central point in so many centuries. The greatest variations were observed by De Langle between Greenland and Labrador, which was 45° west, and by Capt. Cook in 60° south latitude, and 92° 35′ longitude, when it was 43° 6′ east of the geographical meridian.

To illustrate the magnetism of the earth, Professor Barlow made an artificial globe, and laying wires over it subject to electrical induction, arrived at some singular results; the following is an account in the learned professor's own words:

"I procured a wooden globe, sixteen inches in diameter, which was made hollow for the purpose of reducing its weight, and while still in the lathe, grooves were cut to represent an equator and parallels of latitude at every 4½° each way from the equator to the poles; these grooves were about one-eighth of an inch deep and broad; and lastly, a groove of the same breadth, but of double the depth, was cut like a meridian from pole to pole half round. These grooves were for laying in the wire, which was effected thus: the middle of a copper wire nearly ninety feet long, and one-tenth of an inch in diameter, was applied to the equatorial groove, so as to meet in the transverse meridian; it was then made to pass round this parallel, returned again along the meridian to the next parallel, and then passed round this again, and so on, till the wire was thus led in continuation from pole to pole.

"The length of wire still remaining at each pole was bound with varnished silk, to prevent contact, and then returned from each pole along the meridian groove to the equator. At this point, each wire being fastened down with small staples, the wires for the remaining five feet were bound together to near their extremity, where they opened to form two points for connecting the poles of a powerful compound voltaic battery.

"When this connexion was made the wire became, of course, an electric conductor, and the whole surface of the globe was put into a state of transient magnetic induction; and, consequently, agreeable to the laws of action above described, a neutralised needle freely suspended above such a globe would arrange itself in a plane passing from pole to pole through the centre, and take different angles of inclination, according to its situation between the equator and either pole.

"In order to render the experiment more strongly representative of the actual state of the earth, the globe in the state above described was covered by the gores of a common globe, which were laid on so as to bring the poles of this wire arrangement into the situation of the earth's magnetic

poles, according to the best observations we have for this determination; I therefore placed them in latitude 72° north, and 72° south, and on the meridian corresponding with 76° west, by which means the magnetic and true equators cut one another at about 14° east and 166° west longitude.

"The globe being thus completed, a delicate needle must be suspended above it, neutralised from the effect of the earth's magnetism, according to the principle I employed in my observations on the daily variation, and described in the *Philosophical Transactions* for 1833; by which means it will become entirely under the superficial galvanic arrangement just described. Conceive the globe now to be placed so as to bring London into the zenith, then the two ends of the conducting wire being connected with the poles of a powerful battery, it will be seen immediately that the needle, which was before indifferent to any direction, will have its north end depressed about 70°, as nearly as the eye can judge; *which is the actual dip in London.* If now we turn the globe about on its support, so as to bring to the zenith places equally distant with England from the magnetic pole, we shall find the dip remains the same; but the variation will continually change, being first zero, and then gradually increasing eastward, as happens on the earth. If, again, we turn the globe so as to make the pole approach the zenith, the dip will increase, till at the pole itself the needle will become perfectly vertical. Making now this pole recede, the dip will decrease, till at the equator it vanishes, the needle becoming horizontal; continuing the motion, and approaching the south pole, the south end of the needle will be found to dip, increasing continually from the equator to the pole, where it becomes again vertical, but reversed as regards its verticality at the north pole."

The magnetic variations, and more especially those influencing the meteorologic changes on the earth's surface, now receive a large amount of attention from scientific men in all parts of the globe. The Government have caused to be erected a Royal Observatory at Greenwich for magnetic and meteorological observation, under the direction of James Glaisher, Esq., F.R.S., who has, at a vast amount of personal labour, reduced his practice to a system, and succeeded in establishing, in various parts of the country, fifty other stations for meteorological observations; all are in daily communication, and the results are considered so important, that they form a part of the quarterly Reports of the Registrar-General. The Board of Ordnance have likewise ordered Colonel Sykes to prepare twenty sets of instruments for as many stations to be immediately established in India. It may not prove uninteresting to our readers to be furnished with a history of the more important instruments in daily use at the Royal Observatory at Greenwich.

"In the beginning of 1836, the Astronomer Royal, Mr. Airy, submitted to the Board of Visitors of the Royal Observatory a plan for the erection of a Magnetical Observatory; in consequence of the interest taken in the proposal by the Board of Visitors, the building was erected in the spring of 1838, and observations were taken in it in 1839, on days pre-arranged for simultaneous observations. In the summer of 1839, Mr. Airy recommended to government the prosecution of magnetical and meteorological observations at Greenwich, in correspondence with the observations of Captain Ross in the antarctic expedition, and with the observatories erected under the authority of the Board of Ordnance and

the East India Company in several foreign stations. On government assenting, immediate measures were taken for carrying out the whole plan.

THE OBSERVATIONS.

From November 9, 1840, begins the series of observations which is properly characteristic of the Observatory. Regular observations have since been taken, without intermission, except on Sundays. The regular work of the establishment is: At every even hour of Göttengen mean time (night and day), except on Sundays, to observe the position of each of the three magnets, with the readings of the thermometers enclosed in their boxes; the barometer, and the wet and dry thermometer; to inspect the electrical instruments; to record the direction and estimated strength of the wind; to estimate the proportion of the sky which is covered by cloud, and to note the kind of cloud; to observe whether there be different currents in the atmosphere; and any other meteorological phenomena that may occur; to observe the dew-point four times a day; to observe the inclination of the magnet to the horizon (technically called the dip) four times in the week; incessant observations of the magnets when aurora, or any other unusual circumstance, seems to make it desirable; to observe incessantly whenever the electrical instruments are affected; to observe the three magnets at intervals of 2½ minutes during twenty-four hours on one term-day in each month; to adjust the papers, &c. for the self-registering anenometers; to ascertain the quantity of rain collected at four different heights above the ground each day; occasional observations on the measures of halos, coronæ, and glories, the measures of solar and terrestrial radiation, the intensity of the sun's rays, &c.

It will perhaps contribute to clearness if each magnetic instrument be separately described.

The annexed cut represents the declination-magnet: *a*, a perspective view of the magnet; *b*, a brass frame, carrying a lens; *c*, a brass frame,

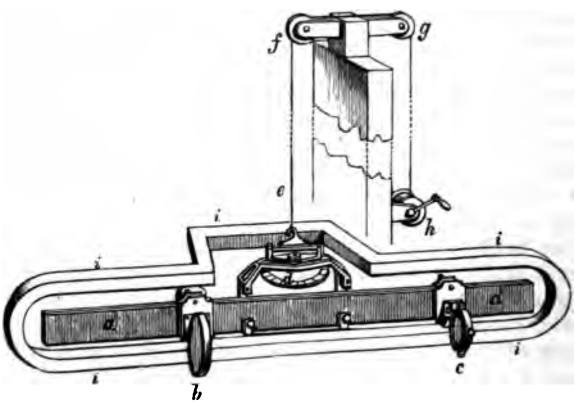


fig. 288. The Declination-Magnet.

carrying two plane glasses, between which is a cross of delicate cobwebs; *d*, the lower part of the suspension apparatus, with the torsion-circle

attached; *e*, the suspending skein of silk fibre, which rises 8 feet 9 inches, then passes over a pulley at *f*, and then over another at *g*, and is then attached to a piece of leather which passes down to a small windlass at *h*, used for raising or lowering the magnet; *i*, a copper bar, about one inch square, used to check the vibration of the magnet.

The magnet is a bar 2 feet long, 1½ inch broad, and about a quarter of an inch thick. It is of hard steel throughout.

Upon the cross-bars of the stand rests a double rectangular box, covered with gilt paper on the interior and exterior sides of both, one box being completely enclosed within the other. Within these the magnet vibrates freely.

At the distance of eight feet from the centre of the magnet is placed a theodolite, on a stone pier firmly fixed in the ground, and unconnected with the floor. The telescope of the theodolite is generally directed to the cross of cob-webs carried by the magnet, which therefore moves as the magnet moves; a record of the apparent position of the cross, as seen in the telescope, will denote the position of the magnet with respect to the reading of the divided limb of the theodolite.

The theodolite-telescope can be turned so as to observe stars as they pass the north astronomical meridian through an opening in the roof. The difference between the reading of the theodolite when directed to the south astronomical meridian, and its reading when the telescope is directed to the magnet, when corrected for disturbing causes, to be alluded to presently, is the magnetic declination, or the inclination of the magnet to the astronomical meridian, or, popularly, the variation of the compass. Great care has been bestowed upon determining the effects of each pair of magnets upon the third, and their effect is allowed for in the reductions; also the effect of the mean-time clock has been found: careful experiments have been made upon every thing near the magnets that possibly might have some effect on them; such as the fire-grate in the ante-room, the bars of which are of iron, the iron about the electrometer-pole, &c., and when the effect is sensible it is taken into account in the reductions: this remark applies to every magnet in the Observatory.

The amount of the magnetic declination is found to be different at different times of the day, being greatest at about 1 P.M.; the north end of the magnet then moves towards the east, or the magnet approaches the astronomical meridian, till six or eight in the evening, the declination at the latter time being about ten minutes of a degree less than it was at the former time; the north end then recedes from the astronomical meridian till about two o'clock in the morning, it then moves in the contrary direction till four o'clock, at which time it again changes the direction of its motion, and approaches the astronomical meridian till six or eight in the morning, when it again begins to move from the meridian. Thus the diurnal movement consists of a double approach to, and a double receding from, the astronomical meridian every day.

The mean diurnal change in the position of the magnet is about 14 minutes of a degree in the summer, and about 2 minutes less in the winter; but there are some days on which the whole arc may not be more than three minutes, and on others it may be more than a degree.

Next is a view of the horizontal-force magnet (fig. 289), viewed from

a position south-west of it: *a*, the magnet; *b*, the mirror carried by the magnet, with the screws for adjustment; *c*, the torsion-circle; *d*, the system of five pairs of small pulleys; *e*, *e*, two halves of a skein of silk,

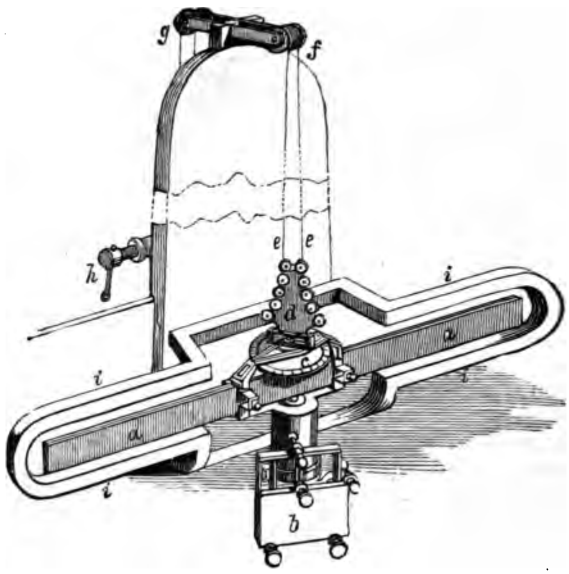


fig. 289. The Horizontal-Force Magnet.

which rise from the upper pair of pulleys to another pair of pulleys, 7 feet 9 inches above them, *f*; then over the pulleys at *g*, and so down and over a single large pulley, not shewn in the drawing, whose axis is attached to a string that passes down to the windlass, the handle of which is represented at *h*; *i*, a copper bar encircling the whole magnet.

The magnet is of the same dimensions as the declination-magnet. It is supported by a broad tripod stand, resting on the ground, and not touching the floor. The stand rises 11 feet 5 inches above the floor, carrying at the top the pulleys for the suspension of the magnet, represented at *f* and *g*. The magnet vibrates in a double rectangular box, similar to that in which the declination-magnet vibrates. Part of the south side of the box is of plate glass.

At the distance of 8 feet 5 inches due south of the magnet is fixed to the wall of the east arm a scale of numbers; these numbers are seen with a fixed telescope directed to the mirror which the magnet carries. The telescope is fixed to a wooden tripod stand, whose feet pass through the floor without touching it, and are firmly connected with piles driven into the ground. Its position is shewn (at *e*) in the ground-plan; and it is such that an observer, sitting in a chair at *o*, can, by turning his head, look into the telescope of any one of the three magnets. This magnet is placed very nearly transverse to the magnetic meridian, and held there by

the directive power of the two halves of the suspending skein *e, e*. The magnet is constantly endeavouring to move to the magnetic meridian, or parallel to the declination-magnet; and as the magnetic power increases or diminishes, the two threads of the suspending skein become more or less twisted, and different numbers of the scale are seen in the observing telescope, from which the variations of the force are determined. It is found that at about noon the magnetic force is least, as the magnet is the least drawn towards the north. It then moves toward the north till about 6 P.M.; it remains nearly stationary till 11 P.M.; it moves again towards north, is checked in its motion again at about 4 A.M., and arrives at 6 A.M. with its marked end at the extreme north position.

The next cut (fig. 290) represents the south view of the vertical-force magnet. *a*, the magnet. *b*, the mirror carried by the magnet, with the

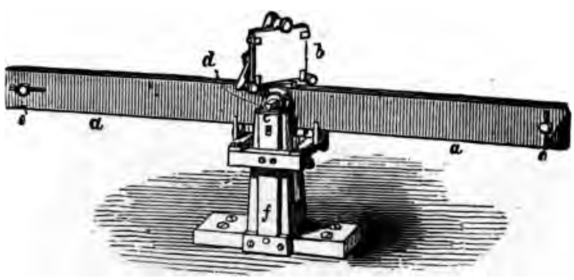


fig. 290. The Vertical-Force Magnet.

screws for adjustment. *c*, one of the two steel knife-edges, similar to the knife-edge of a balance or pendulum. *d*, one of the two agate planes, on which the knife-edges rest. *e, e*, screws by which the elevation of the centre of gravity and the inclination of the magnet in its position of rest can be altered. *f*, a brass frame on which the instrument is placed.

This magnet is of the same dimensions as the other two magnets. It is supported upon a block, connected with a tripod stand, which passes through the floor and rests on the ground. Its position is, as nearly as possible, symmetrical with that of the horizontal-force magnet in the opposite arm. The whole is enclosed in a similar double-box to those in which the other magnets vibrate, resting on the block of wood above mentioned. In this box the magnet vibrates freely up and down. A part of the south side of the box is of plate-glass. A tripod stand (symmetrical in form and position with that for carrying the telescope of the horizontal-force magnet) carries a telescope, which, being directed towards the mirror, the observer sees in the telescope the numbers on the scale, which is vertical and fixed to the stand carrying the telescope. As the magnet inclines more or less to the horizon, the numbers on the scale, as seen through the telescope, increase or diminish, from which the variations of the vertical force are determined. It is found that at two o'clock in the morning the marked end of this magnet is less drawn downwards, and at four P.M. it is more drawn down than at any other time in the day.

The cut (fig. 291) represents the apparatus at the top of the electrical pole: *a*, the lantern at the top (the lamp is always burning); *b*, the

copper tube on which the lantern slides; *c*, the dotted lines represent a cone of glass, on which the copper tube carrying the umbrella *h* above is

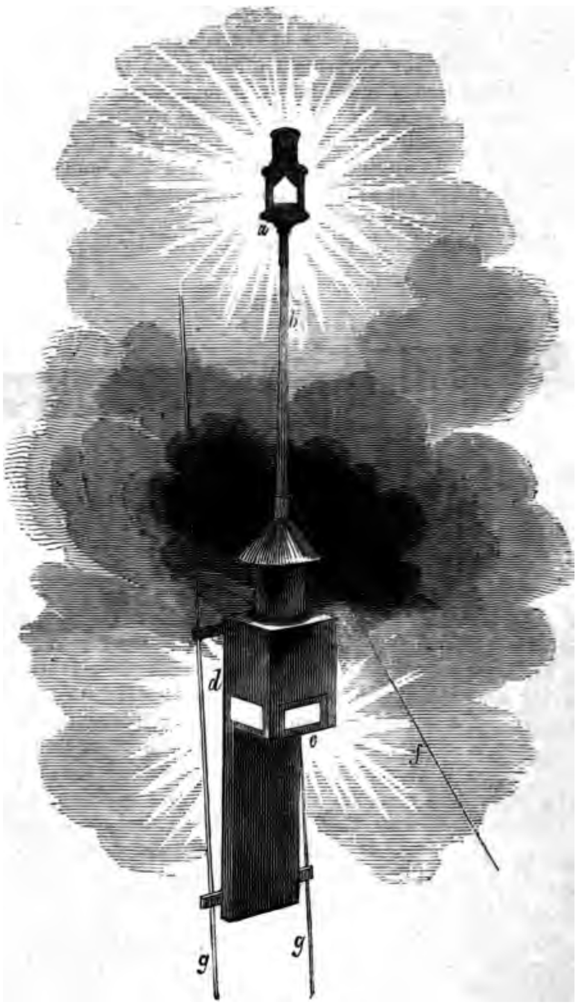


fig. 291. The Electric Light and Apparatus.

fixed, to protect the glass from rain, &c.; *d*, a wooden apparatus enclosing the lower part of the cone of glass: the lower part of the glass is hollowed out and lined with copper, immediately under which is placed a lamp, represented in the drawing at *e*, which is constantly kept burning for the purpose of heating the copper, and thus keeping the glass dry; *f*, the wire communicating with the electrical instruments in the ante-room; *g*, *g*, iron rods upon which the whole apparatus slides up and down.

The electrical apparatus, as it appears in the window of the ante-room, is represented in the next cut (fig. 292). *a*, the hook, representing the

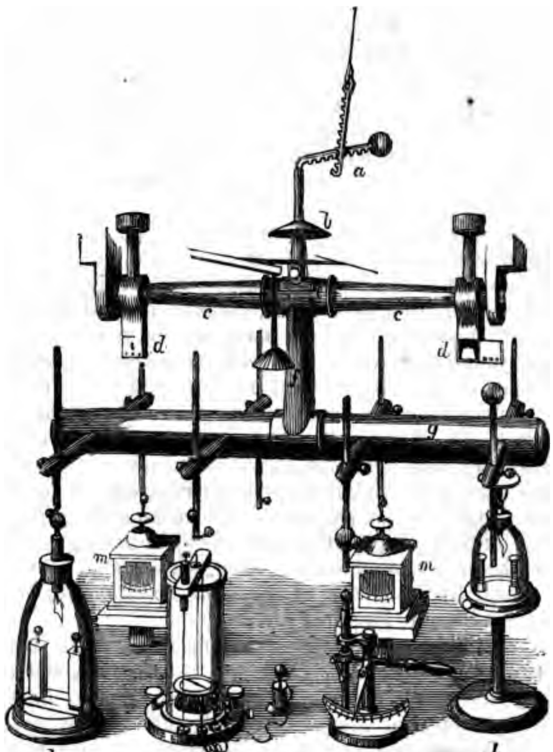


fig. 292. The Electric Bell and Apparatus.

connection of the conducting wire with the apparatus; *b*, an umbrella to cover the opening in the upper part of the window, through which an upright rod passes, carrying the apparatus below; *c, c*, a double cone of glass supported by the upper part of the window by brackets at each end; *d, d*, lamps placed nearly at the end of each cone of glass, for the purpose of keeping the glass dry; *e*, a collar encircling the glass, and by means of the vertical rod *f* supporting the hollow copper tube *g*, carrying the several electrical rods, which can be moved upwards and downwards, and by this means brought into connection with the electrical instruments immediately underneath, and can be fixed by screws in any position; *h*, a Bohnenburger's single-leaf pendent gold-leaf electroscope, and a pair of Zamboni's dry electric piles: this instrument is extremely sensible to slight changes of electrical excitation, and it indicates in a marked manner not only the presence but the kind of electricity; *i*, a galvanometer, for exhibiting currents of electricity in the atmosphere; *k*, an instrument to measure the lengths of the electrical sparks; *l*, another dry-pile apparatus similar to *h*, but less sensitive; *m, m*, straw electrometers, much used in observing

electrical changes in the atmosphere. They are furnished with graduated arcs, to estimate the amount of the electric force.

In order to collect the electricity, a lamp is constantly kept burning in the lantern *a*, fig. 291. The glass cone below it being kept dry is a non-conductor; therefore, the only way that the electricity can escape is down the wire *f*, and so to the several instruments *h*, *i*, *k*, *l*, *m* and *m*. As this apparatus has not been long in use, it would be premature to say much about the results; but, however, it seems certain that on the first appearance of fog, rain, snow, hail, or sleet, the electricity is generally negative, and often highly so; but it afterwards undergoes frequent transitions to positive, and then again negative.

Electric sparks are frequently obtained. The colour of the spark is blue, and frequently violet and purple.

The method hitherto adopted for observing the indication of these instruments has been that of viewing, through a fixed telescope, the divisions of a fixed scale reflected by a plane mirror attached to each magnet. But by this system of observation a very imperfect knowledge of the nature of magnetic changes has been obtained; and as it has been deemed necessary, in magnetic observatories, that the observations of the various instruments should be made at intervals of at furthest two hours, by night as well as by day, this laborious duty has devolved upon the assistants; hence some means of enabling these instruments to record their own changes has long been an acknowledged desideratum in physical science. With the aid of photography, this desired object has been attained by the instrument, the merit of which has been acknowledged by the award of a council medal by the jurors of the Great Exhibiton of 1851 to the inventor, Charles Brooke, Esq., Surgeon.

By Mr. Brooke's self-registering apparatus an uninterrupted and unerring record of all magnetic changes is now maintained at the Royal Observatory, Greenwich. These results could not have been obtained by personal observation; for even if every telescope were constantly watched by the eye of an assistant (which would require a very numerous staff), the results would still be liable to errors of observation; and occasionally the magnetic variations are too rapid and transient to be continuously recorded by an observer. We may further remark, that since the employment of this apparatus at Greenwich, the number of assistants in the magnetic department has been reduced, and the fatigue of night duty has been dispensed with entirely.

Magnetic registration is undoubtedly the most useful application hitherto made of the beautiful art of photography. The method suitably applied to each of the magnetic instruments may be thus described:—A concave metallic mirror three inches in diameter is attached to each magnet by a frame possessing all requisite adjustments; the rays of light from a lamp or gas-burner, placed at a distance of about two feet from the mirror, pass through a small aperture in a metallic plate, and fall on the mirror, whence they are reflected to a focus at a certain distance. The source of light being fixed, it is clear that the movements of the focal point of light will correspond with those of the magnet. A cylinder covered with photographic paper is so placed that the point of light may fall on it. The cylinder is carried round on its axis by clock-work, and, by the combined movements of the point of light and of the cylinder, the

magnetic curve is self-traced upon the sensitive paper. The photographic process has also been applied to the barometer, and to the wet and dry bulb thermometers; but the mode of application is different from the preceding, the light not being reflected from a mirror.

As the preparation of the sensitive paper used in these instruments differs somewhat from the ordinary photographic processes, it may not be inappropriate to describe it:—The paper is first washed with a solution of four grains of isinglass, eight of iodide, and twelve of bromide of potassium, in one fluid ounce of distilled water, and dried quickly by the fire; a considerable quantity of paper may be thus prepared at once. Previously to being placed on the cylinder, the paper is washed over with a solution of fifty grains of nitrate of silver to one ounce of water, which communicates to it the requisite degree of sensibility. After having been in action for twenty-four hours, the paper is removed from the cylinder, and the impression developed with a warm solution of twenty grains of gallic acid to one ounce of water, with a small addition of the ordinary commercial strong acetic acid: this is subsequently fixed in the usual way with hyposulphate of soda.

The principle of the photographic part of the apparatus is shewn in the annexed cut (fig. 293), in which *a* represents a part of a bar magnet;

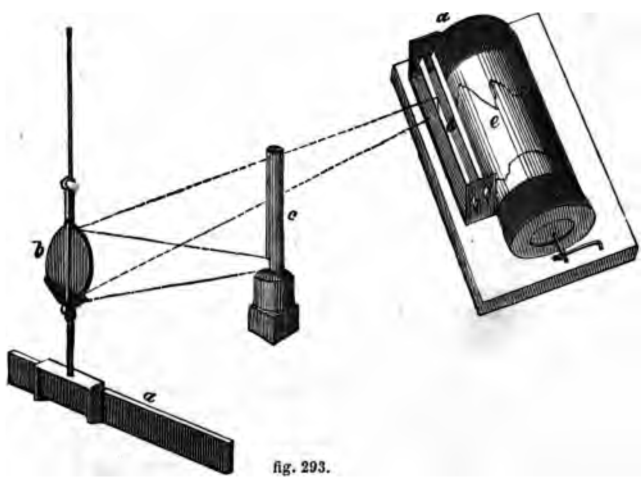


fig. 293.

b a concave mirror, resting in a stirrup firmly attached to the suspension apparatus, the whole being supported by a single thread; *e* a blackened glass cylinder, wrapped round with photographic paper; *d* a plano-convex lens; *c* a lamp placed a little out of the line which joins the centres of the cylinder and magnet. In operation a pencil of light passes from *c* through a very narrow slit or aperture, diverges and spreads over the mirror *b*, from which it is reflected, and diverges to the lens *d*, and is condensed into a well-defined spot of light at the surface of the paper. The action of this spot upon the photographic paper is to leave a trace, which is, however, imperceptible, until removed and developed in the manner pointed out.

As the whole of the suspension apparatus is firmly fixed together, the mirror partakes of every movement of the magnet, and reflecting the spot of light to different parts of the paper, according to the communicated movements, causes the photographic action created by the spot to become a record of the movements of the magnet with which it is identified.

The undulations in the trace, when developed, are thus in exact accordance with the deflexion of the magnet to the right and left; a period of rest, during which time the spot remains stationary, being indicated by an undeviating line, the continuity of which remains unbroken, as the cylinder is placed in gear with a chronometer by means of the winch-iron at the end of the cylinder, resting in the hand of the chronometer, forked for its reception, which revolves once in twelve hours.

Our space will not allow us to detail the many other instruments in daily use at this active observatory. The following are some of the results which are constantly deduced:—the mean position on every day, in every month, in quarterly periods, and for the year; also at every hour, in every month, in quarterly periods, and for the year, of the following instruments:

Those of the three magnets which we have described.

From the observations of the barometer, its mean height.

From the observations of the dry thermometer, the mean temperature.

From the observations of the dry and wet thermometer are deduced;

The temperature of the dew point.

The elastic force of vapour in the atmosphere.

The weight of a cubic foot of air.

The weight of the moisture in a cubic foot of air.

The degree of moisture in the air—when completely saturated, being considered as unity.

From the anemometer, &c., the direction and strength of the wind.

From the observations of the clouds, their mean state.

From the observations of the rain collected, its quantity, and many other results.

The business of the observatory, it will be seen, embraces magnetism, electricity, and meteorology, in their fullest senses.

Philosophers long puzzled themselves in endeavouring to trace the relation of electricity, galvanism, and magnetism to each other, and to find out the law by which polarity was given to steel bars by means of electricity; but nothing conveying any conviction to the mind was discovered until the year 1819, when Professor Œrsted, of Copenhagen, threw considerable light on the subject by the announcement of the success of investigations that have formed the foundation of the science of electro-magnetism. This great discovery of modern times is yet in its infancy, but is believed to be fruitful with important results to mankind, as its details become understood and its economical application can be achieved.

Œrsted stated that if a magnetic needle, free to move, be brought parallel to a wire conveying electricity, it would leave its natural position and take up a new one, dependent on the position of the wire and needle to each other. That if the needle be placed horizontally under the wire, the pole of the needle nearest the negative end of the battery will always move westward; but if the needle be placed above the wire, the same pole will move eastward. If the needle be placed in the same horizontal plane as

the wire, no motion takes place in that plane, but it inclines to a vertical action; when the wire is to the west of the needle, the pole nearest the negative side of the battery is depressed, but when it is on the eastern side it is elevated. From these phenomena Œrsted concluded that the magnetic action of the electricity moved in a circular manner round the conducting object. When a wire connects the two extremities of a voltaic battery, it is termed by Œrsted the conjunctive wire. By bringing the north pole of a magnetic needle below and at right angles to the platinum wire, it will be repelled, but if above it attraction will take place. Reverse the poles of the needle, and the results will be reversed.

To facilitate the memory Professor Œrsted proposed the following formula: "The pole *above* which the negative electricity enters is turned to the west; but if *under*, to the east."

To exemplify electro-magnetic rotation, Faraday constructed a delicate apparatus (fig. 294). It consists of a vessel nearly full of mercury; in the centre of the bottom of the cup a copper wire, *a b*, was inserted, a cylindrical magnet *e, f* was fastened by a thread to the wire, and the north pole of the magnet only projected above the mercury; *c, d,* a conductor, was inserted in the mercury exactly over *a*. The wires of a battery were then attached, and as the current passed through the mercury from one wire to another, the magnet rotated about it. If the positive current descended, the rotation was in the direction from east through south to west; but if the current was made to ascend, then the direction of the motion was reversed.

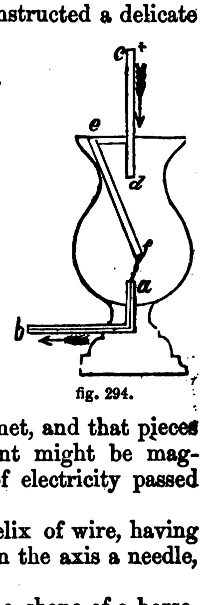


fig. 294.

The ingenious experiments of Ampère in France, and Davy in England, fully testified that the conjunctive wire becomes possessed of all the properties of a magnet, and that pieces of steel placed at right angles to an electric current might be magnetised to a degree correspondent to the amount of electricity passed round it.

Arago, under the direction of Ampère, formed a helix of wire, having at each end a small cup of mercury, and on placing in the axis a needle, it became instantly magnetised (fig. 295).

Now if we take a piece of soft iron somewhat in the shape of a horseshoe, then coil round it cotton or silk-covered copper wire, the ends of

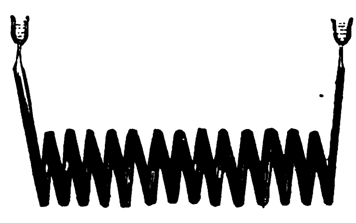


fig. 295.

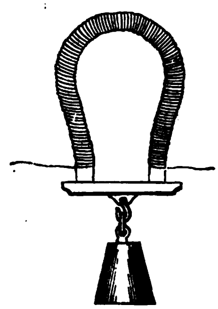


fig. 296.

which we unite to the extremities of a voltaic battery, we shall create an electro-magnet of enormous power.

These magnets are temporary, their power only lasting while the electrical current is passing through the wire. In this respect soft iron differs from steel, as the latter acquires magnetism more slowly, and retains it after the exciting cause has ceased. The cotton or silk wound round the copper wire is to insulate it throughout its course. A magnet has been found on this principle capable of sustaining upwards of one ton six cwt., while the magnet and its coil were not more than 35 lbs. weight. A magnet exhibited in London, at an eighth of an inch distance, attracted iron with a force of 1344 lbs., and required more than two tons force to separate it when in contact.

One peculiarity attends the electro-magnet, which is, that although capable of sustaining this immense weight, the attractive power extends but a short distance.

The discovery being made that magnets, illimitable in power, were within the constructive abilities of man, attention naturally was given to their application as a motive-power. The advantages of such a power, in certain respects, over steam were self-evident, from its noiseless action, portability, safety, controllability, and freedom from dirt. Professor Jacobi, assisted by the Russian government, succeeded in propelling a boat upon the Neva at a rate surpassing that of the first attempts at steam-navigation. In his experiments in 1839 he had a boat 28 feet in length and $7\frac{1}{2}$ in width, which drew about 3 feet water. Ten persons were on board, and the paddles were moved by an engine worked by a Grove's battery of 64 pairs, each platinum plate having 36 square inches of surface. The speed attained was four miles an hour. The Russian philosopher has also applied the power to various machines, but not yet with decided success.

Mr. Robert Davidson attempted in 1842 its application to railway purposes, and succeeded in propelling a carriage weighing five tons at the rate of four miles an hour on the Edinburgh and Glasgow Railway.

Mr. Davenport and Professor Page, in America, have made several attempts to accomplish the motion of machinery by electro-magnetism in lieu of steam. The professor, most properly, has been aided by congress in his experiments; and very successfully caused engines to be moved of considerable power. He has also worked a printing-machine of four horse-power, and a trip-hammer which he controlled at a slow or rapid speed with the utmost facility.

An ingenious Danish gentleman, named Hjorth, took out a patent in 1849 for an electro-magnetic motive engine, which appeared to approach perfection. It was of ten horse-power, and one of the electro-magnets was capable of supporting 5000 lbs. weight; at a distance of one-eighth of an inch its attractive force was equal to 1500 lbs.

Although many scientific persons scout the possibility of its superseding steam, still we would advise modesty in such assertions; for it must be remembered that when it was first suggested to light towns with gas, the greatest chemist of the time, Davy, recommended the parties, as an easier method of accomplishing their object, to cut a slice off the moon. In oceanic steam-navigation, Dr. Lardner proved to the British Association of Science, most satisfactorily, its utter impracticability in a

commercial point of view. Stephenson was laughed at by the learned legislatures of our country when he ventured to state he could move carriages on railways, by locomotive power, twenty miles an hour. Yet all these objects are fully attained.

The motive-power of electro-magnetism has been most successfully applied to the mechanism of time-keepers. Clocks are now found in action at the principal railway-stations, chronometer-makers, and telegraph-offices in the kingdom; many private establishments have adopted them, and find they will go a longer period than the ordinary time-pieces, at a cost of under a penny per week, and their regularity can be thoroughly depended upon. As Greenwich time is that adopted by all railway companies for the guidance of the departure of their trains, there are few local clocks that are in accordance with it, which leads to many painful and serious disappointments; it has therefore been proposed to establish apparatus at Greenwich which shall regulate a public clock in each town, for the guidance of railway travellers; and we have no doubt at no distant date this arrangement will be effected, in the same way as it is at the electric-telegraph office in the Strand.

At the Great Exhibition held in London 1851, amongst the many illustrations of the genius of man, it was deemed necessary to have an electro-magnetic clock, the construction of which was entrusted to Mr. Shepherd, and ornamented the south end of the building.

Faraday was the first person who demonstrated that from ordinary magnets a continuous stream of electricity could be produced. In a variety of ingenious methods he rendered this plain. He had a curved bar of soft iron, around which he wound 500 feet of copper wire, leaving the ends bare; the ends of the wires he connected with a delicate galvanometer; on bringing the ends of the soft iron in contact with the ends of the magnet, he obtained the usual indications of the presence of electricity; and on breaking contact the needle was again deflected, but in the opposite direction. M. Hipolyte Pixii, of Paris, followed up the discovery of Faraday. With a coil of 3000 feet of wire round a curved bar of soft iron, which bar he placed very near the ends of the permanent magnet, and causing the magnet to revolve round very rapidly, making and breaking contact every time the poles passed the ends of the bar, he produced a continuous and rapid succession of brilliant sparks; this was the first magneto-electric machine. In 1833 and 1835 this instrument was improved by Mr. Saxton, who, instead of causing the magnet to revolve, had a double *armature* which turned round. By this magneto-electric machine, represented in the accompanying figure, 298, a continuous stream of electricity may be produced of sufficient force to give violent shocks, to melt metals, and to exhibit most of the phenomena of a powerful voltaic-battery. The principal parts of the instrument consist of a strong compound permanent steel magnet *a b*; and two combined pieces of soft iron *c d* covered with helices of copper wire, and fixed on an axis, so as to rotate in close proximity to the surfaces of the permanent magnet. A multiplying-wheel *e* gives rapid rotary motion to the soft iron armature, the ends of the wire round which are so arranged

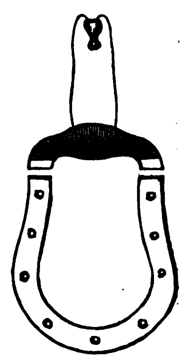


fig. 297.

that contact is made and broken at each revolution; and at every break of contact a current of electricity is evolved.

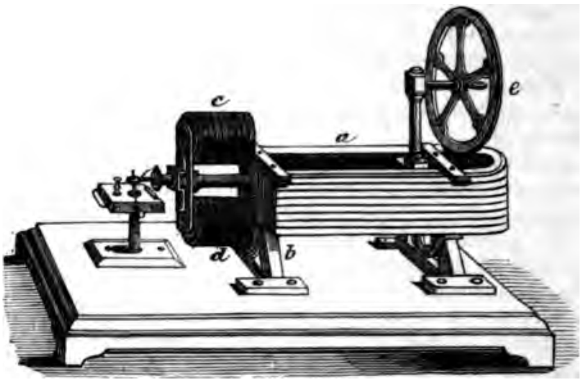


fig. 298.

The late Mr. William Sturgeon, the Lancashire shoemaker and soldier, who raised himself by his talents to the chair of experimental philosophy in the Honourable East India Company's Military Academy at Addiscombe, and afterwards became lecturer to the Royal Historic Gallery of Practical Science in Manchester, contributed greatly to the promotion of electrical science. He stated about 1835, that he contrived a magnetic-electro machine by which he coated metals with tin, copper, &c., and that he employed it with advantage in gilding, silvering, and platinising various kinds of metal of inferior value.

Among the interesting contributions to electrical science, we must not omit to notice Faraday's discovery that a ray of light may be electrified, and that lines of magnetic force may be rendered luminous. He has also discovered that oxygen gas possesses magnetic properties, which vary with its expansion by heat. The latter discovery is supposed to throw important light on the phenomena of terrestrial magnetism; but the subject is too recondite for consideration in an elementary treatise, and the results of these interesting investigations will be fully entered upon in another book almost exclusively devoted to magnetism.

Of all the remote and recent achievements of science the Electro-Magnetic Telegraph is the most wonderful. By it, space is annihilated and time beaten—light in its swift flight is out-distanced—news speeds along insensate wire buried in the earth, sunk in the ocean, or stretched on poles, telling of the fall of empires or the flight of kings, the price of stocks, of births and bankruptcies, of arrivals and accidents, of elopements and wrecks, of crops, of robberies, of murders, and of markets. Friends hundreds of miles distant may converse as if in the same apartment; nay, may print what they wish announced; or write, and by their hand prove their identity. Journeys are saved, feelings are soothed, anxiety banished, safety promoted to person and property, by arresting the murderer or thief, by the magic of this extraordinary invention. Were we asked to explain the speed of this communicator of our ideas to the fullest extent of their ramification, we would answer, Take that stick, lay it on the table, push one end, and by judging when the opposite end moves, you may esti-

mate the time required by the electric telegraph to convey a motion of the needle from one end of the wire to the other.

It was in 1748 that Dr. Watson, Bishop of Llandaff, in company with other scientific persons from Shooter's Hill, laid down a wire on land and through water more than four miles in length, through which he passed the electric current in a space of time that could not be appreciable; and hence he conceived the application of such a means as an excellent system of conveying signals.

The doctor's experiments were repeated on the continent, and in one instance to an extent of twenty-six miles. In 1787, M. Lamond had it in practice in France, but his plan never became popular.

Mr. Ronalds of Hammersmith, in 1816, exhibited a telegraph eight miles in length worked by clocks; and Mr. Sommering invented a very ingenious contrivance for telegraphic purposes.

The discoveries of Œrsted at length gave an impetus to the subject by removing many former obstacles, and the celebrated Ampère at once suggested its applicability to the purpose to which it is now employed. Dr. Ritchie and Davy both exerted themselves to bring the invention to a practical state; but it was not until 1837 that a successful means was developed by Mr. Alexander, of Edinburgh, before the Society of Arts of that capital, and for which he took out a patent in the same year. It was in the form of a chest, and consisted of thirty-one wires, to exhibit the alphabet, stops, and signals. A series of troughs of mercury communicated with a voltaic battery; a series of keys like those of a pianoforte were provided, having a wire run underneath each, by which the communication with the trough of mercury could be made, these being pressed down completed the circuit; each key communicated with a magnetic needle, on which was placed a screen concealing a letter; so that on the depression of a key the current passed to the according needle, which being deflected the letter was uncovered; as soon as the contact ceased, the letter was again hidden.

Many improvements and inventions followed; and at last Professor Wheatstone and W. Fothergill Cooke brought the matter to such perfection, as to cause it to be adopted as a part of the railway-system of the kingdom, and to become a valuable addition to individual and national happiness.

The batteries used for the purposes of the electric telegraph are the same in principle, but a little different in detail, with those we have already described. They consist of a strong wooden water-tight trough, with partitions of slate; the zinc and copper plates are connected by slips of copper to which they are soldered, and which slips support them on the slates. The cells are filled with fine sand, saturated with one part of sulphuric acid to fifteen of water, and according to the distance is the number of cells required. The zinc plates are first amalgamated by leaving them for a short time in a solution of bichloride of mercury, by which they become coated with mercury and more durable. The two wires from the opposite ends of the trough are then ready for use, and are attached to the telegraph. As two wires only are used, without return wires to complete the circuit, a large piece of metal is buried in the earth, to which a branch wire from the telegraph instrument is attached, or it is fastened to the water or gas pipes of towns.

The first act on commencing operations at the electric telegraph instrument from either station is that of ringing a bell, which is performed by what is termed a striking apparatus placed on the top of the instrument, seen in fig. 299, where the attendant is present. This apparatus consists

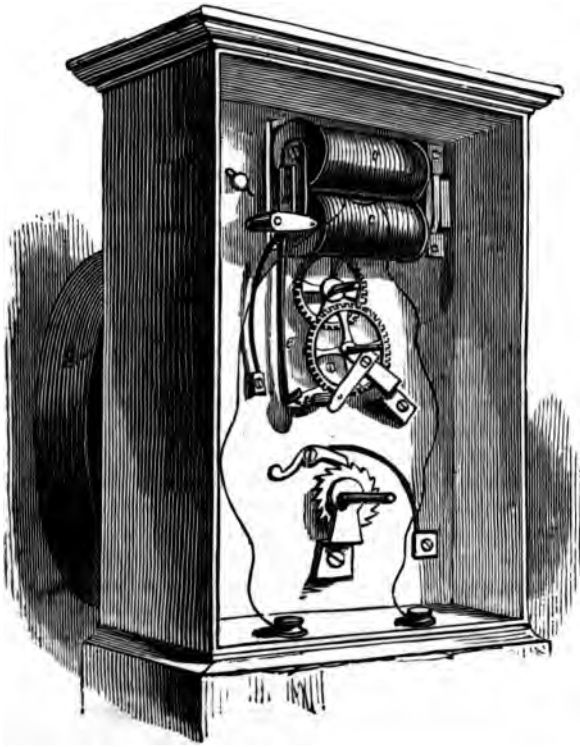


fig. 299. The Striking Apparatus.

of an armature *c c* formed of soft iron with silk-covered fine copper wire, connected together. As soon as the current of electricity passes into them, the iron bar in the centre of each become magnets. At a little distance from them at one end is a piece of soft iron *d;* this is attracted to the magnets, and as it is attached to the bent lever *e,* it moves the lower end, to which there is a catch backward, by which motion the pin *f* is released. The wheels being at liberty, and acted upon by a main spring, they whirl round and give motion to a hammer that strikes the bell *g.* On the left of *e* there is a slight spring that re-acts on the lever and restores it to its position when the attraction of the electro-magnet ceases, and causes the catch again to hold the pin *f.*

As soon as the attendant arrives at the dial to which his attention is called, his first care is to stop the noise of the busy bell, that keeps ringing until attended to. On the left-hand side of the dial-box, fig. 299, there is a brass handle, by turning which the current is made to pass to the wires

of the dial instead of proceeding on to the clock; then the attendant replies with a signal to "go on" or "wait," which sign will be explained afterwards.

As soon as the voltaic force is applied at one end of the wire it is sensibly felt at the other end; and according to the direction in which it arrives at the instrument, the magnetic needle is moved to the right or to the left. This portion of the apparatus is termed the telegraph galvanometer.

Two magnetic coils are made, consisting of very fine silk-covered wire *i k* (fig. 300). These are placed vertically, and within is a needle having its north end downwards, communicating and acting upon another needle, *h*, which is outside the dial or index-plate.

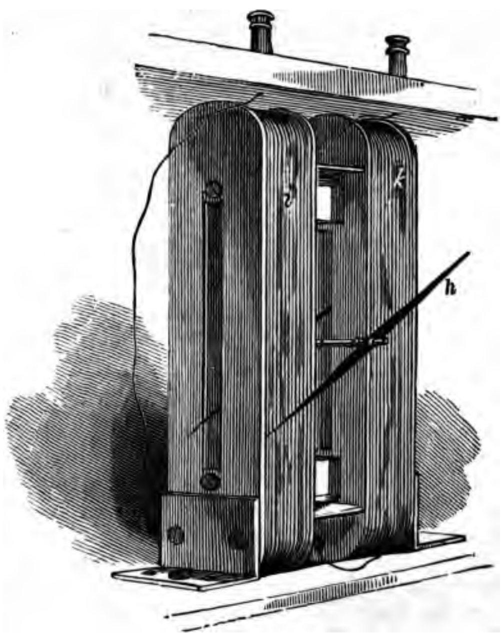


fig. 300. The Coiled Magnets.

The handles seen in fig. 299 turn a wheel or drum, by which the circuit is made instantly either in one direction or the other. This appears by the deflection of the needles at both ends of the line at one and the same time. If the attendant turns the handle so as to send a positive current through the wire, the needle is deflected towards the right hand; and if he turn it in the opposite direction, the needle is deflected towards the left. Thus the movement of the needle is entirely at the command of the operator.

When we watch the working of a telegraph, and see the little delicate needles rapidly move slightly to one side and then to another, and are told this is caused more than a hundred miles distant, and hear the attendant say to the clerk, "Her majesty left Doncaster at 8.40 this morning—all

right;" or, "A carpet-bag was left in carriage 16 last night's up mail-train—forward it to No. — Eaton-square;" or, "Tell the police to keep an eye on a man in the first second-class carriage, dressed in a velveteen shooting-coat, blue neck-handkerchief, curduroy trousers, and narrow-brimmed hat, much turned up at the sides,"—we wonder how such motions can be so interpreted; yet it is actually the easiest acquired alphabet known by which words are spelt.

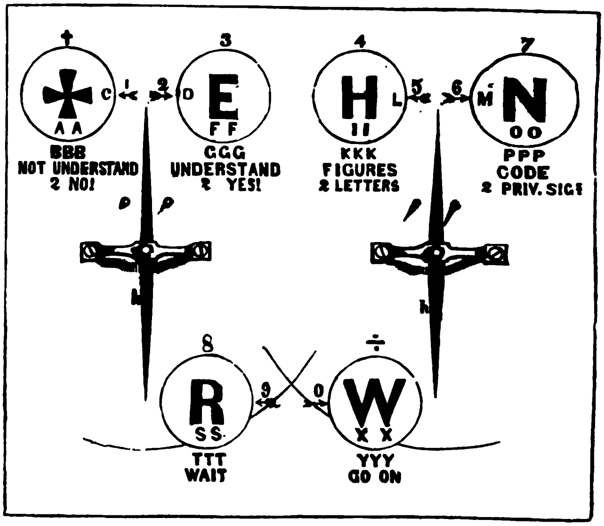


fig. 301. The Index.

When the needle is made to go to the left twice, the letter *a* is meant; when thrice, the letter *b* is intended; and when the pointer goes first to the right, then to the left, the letter *c* is expressed. On the pointer moving to the cross it signifies "stop"—the word is complete; but if the attendant receiving the message does not understand, he makes a return signal of once to the cross, and the other party repeats the word. As each word is received the attendant acknowledges he understands it by pointing once to the letter E on the dial. The letter D is signified by the needle first going to the left, then to the right; E is one motion to the right; F two motions; and G three motions to the right, and so on through the whole alphabet. The technical term for these motions is *beat*. For "yes" one beat is made to E; once to R with both needles to the right signifies "wait," and both needles to the left signify "go on."

In the electric printing-telegraph inked types are brought into contact with the paper by the force of an electro-magnet. The perfection and rapidity of execution are surprising, and on the lines where they are employed have been perfectly successful.

The Copying Electric Telegraph, invented by Mr. F. C. Bakewell, is extremely simple. The messages to be transmitted are written on tinfoil with sealing-wax varnish, and are then applied to a cylinder on the transmitting instrument. A metal style connected with the voltaic battery presses lightly on the writing; and as the cylinder revolves

by the influence of a weight, the metal point is carried by a fine screw, on which it traverses, from the top to the bottom of the lines of writing. By this arrangement the style passes several times over each, but in different parts, of the letters. The receiving instrument resembles

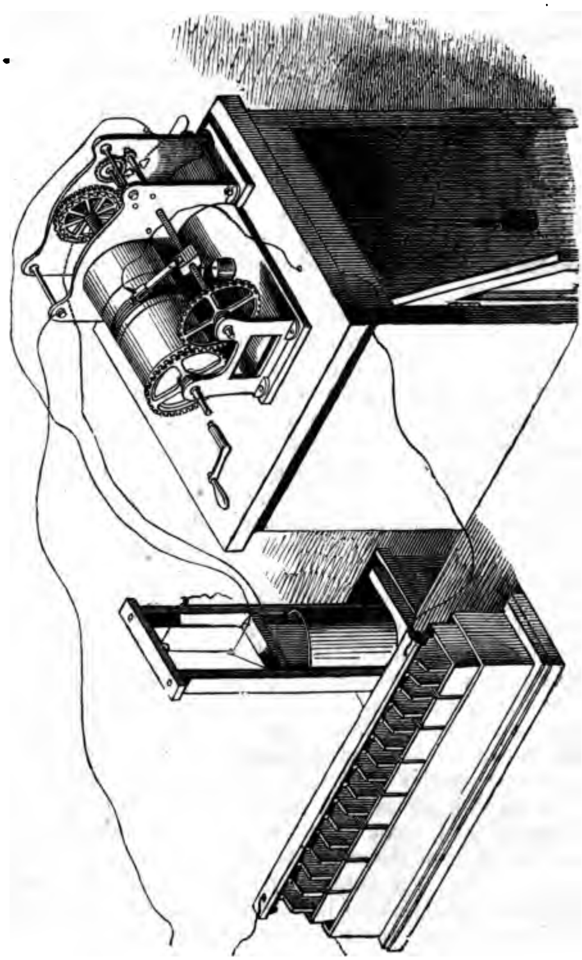


Fig. 302. Bakewell's Copying Electric Telegraph, shewn in connexion with the Galvanic Trough and Magnetic Regulator.

the transmitting one; but on the cylinder of that instrument paper moistened with a solution of prussiate of potass and diluted muriatic acid is applied, and the metal style consists of a piece of fine steel wire. The electric current from the positive pole of the voltaic battery is conducted by a communicating wire to the steel point, and passes through the paper to complete the voltaic circuit. The action of the electricity, when the current is passing, decomposes the muriatic acid, and the steel combining with the chlorine of the acid, a deposition of iron

takes place on the paper, which is instantly converted into prussian blue by the prussiate of potass. By this arrangement, therefore, the steel point of the receiving cylinder draws a succession of blue lines spirally over the paper when the electricity is passing through it; but when the electric current is interrupted by the varnish writing, over which the point of the transmitting cylinder is continually passing, the electric current is momentarily interrupted, and the marking cases. The small intervals caused by the cessation of marking, where the varnish interposes, produces an exact copy of the written message on the paper, the letters appearing nearly white, on a ground composed of blue lines drawn very closely together.

It is essential to the success of the process that the two separate instruments should rotate exactly together; otherwise the receiving paper would present a confusion of marks, instead of legible writing, for the different parts of each letter would be marked irregularly. To produce the synchronous movement, Mr. Bakewell has contrived an electro-magnet regulator, by which means the effect may be produced at whatever distance the instruments may be apart.

The number of times absolutely requisite for the point to pass over each line of writing to make the copy legible is six; but when the screw is fine, and the writing large, the point passes over a greater number of times to bring out the forms of the whole letters.

The rapidity of the process depends on the smallness of the writing, and on the velocity of the revolving cylinders. The usual rate of working is one revolution in two seconds, and at that speed upwards of three hundred letters per minute can be transmitted. The practicability of this plan has been proved by the transmission of written messages between Brighton and London.

The advantages of this means of telegraphic communication are stated to be, entire freedom from error, as the messages transmitted are facsimiles of the original manuscripts; authentication of the communications by the transmission of copies of the handwriting, so that the signatures may be identified; increased rapidity, and consequent economy in the construction of telegraphic lines. The secrecy of correspondence would also be maintained, as the copying telegraph would afford peculiar facility for transmitting messages in cipher. As an additional means of secrecy, the messages may be transmitted invisibly by moistening the paper with diluted muriatic acid alone; the writing being subsequently rendered visible by application of the prussiate of potass, the most delicate test of the presence of iron. The instantaneous appearance of the writing on an apparently blank piece of paper has a very curious and astonishing effect.

The accompanying illustration (fig. 303) shews the form in which the writing is produced at the distant station.

fig. 303.

Mr. G. R. Smith's Comic Electric Telegraph would, no doubt, prove an amusing and instructive toy, as it might be used to illustrate the principle of magnetic induction to children (fig. 304).

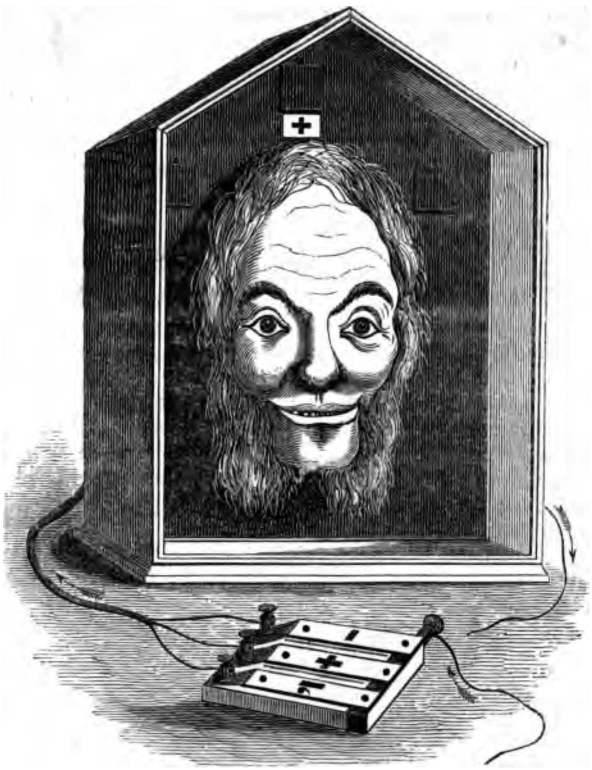


fig. 304.

The action on the eyes and mouth of a comic face is produced by three bent iron bars within the figure, which are rendered magnetic by induction, and attract either of the features as above by means of armatures attached thereto. In addition to these novel signals, there are also the signs —, +, and \, by which not only all the letters of the alphabet are represented, but also the end of each word and sentence respectively properly indicated. These signals are shewn by the elevation of shutters above the face. As each of the bars is capable of being separately magnetised, either of the signals can be shewn at the will of the manipulator, by touching the corresponding key in front of the figure.

In concluding our volume we must notice another triumph achieved by a mind devoted to scientific investigation, and that is, the measurement of the duration of an electrical spark, and of the rate of its passage along a wire, by Professor Wheatstone. By an ingeniously contrived apparatus he proved that the duration of a spark never exceeds a millionth

part of a second, and that its velocity along wire is 288,000 miles in a second!

The learned professor, to illustrate that by this transient light an object in rapid motion might be viewed as if at rest, had a circular disc divided into three compartments, on which he painted the three primitive colours, red, blue, and yellow. This he caused to revolve with great velocity, until the three colours appeared nearly white. He next darkened the room, and threw the light of an electric spark on the disc, when the spectators saw the colours as if the disc were at perfect rest.

This gave an idea to Mr. Talbot in improving the value of the photographic process. He produced an extremely sensitive prepared piece of paper, and in June 1851, at the Royal Institution, placed it in a camera directed to a printed paper fixed on a wheel. The wheel was turned by a handle until the greatest velocity was attained that could be given to it. The camera was then opened, and a powerful electric battery was discharged in front of the wheel, illuminating it with a sudden flash of brilliant light. The paper was then taken out of the camera, and after applying the developing solution, a distinct image of the printed words was found beautifully impressed on the paper.

Thus, then, the last convulsive strain of a Flying Childers at a winning-post may be caught as it truly existed; or an express train, moving at a rate beyond muscular powers in an animal, or more speedy than the wings of the wind, may be transferred to a photographic plate as if it were at rest; for the utmost speed that can be given by man is but rest in comparison to the flight of electricity.

What, after this, is the most brilliant conception of the human mind in the region of imagination? True demonstrable poetry exists in the world of science.

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